

THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 31

JULY-AUGUST, 1946

Nos. 7 and 8

THE BRANCHVILLE, CONNECTICUT, PEGMATITE*

VINCENT E. SHAININ

ABSTRACT

The Branchville pegmatite is a distinctly zoned body that has a complex history. In the first stage the following zones appear to have formed by successive deposition from the walls inward: border zone, muscovite-quartz zone, perthite zone, and quartz core. In the second stage, replacement bodies composed of cleavelandite-quartz, cleavelandite, and cleavelandite-spodumene were developed, at the expense of the zones, along the interzonal contacts. Books of sheet-bearing mica were replaced in parts of the muscovite-quartz zone and most of the microcline-perthite zone was replaced by cleavelandite and quartz. The third stage consisted of supergene alteration of previously formed minerals by circulating ground water.

INTRODUCTION

An unusual pegmatite in the village of Branchville, Connecticut, has long been a renowned locality for manganese phosphates as well as a source of commercial minerals. Nine minerals were first described from the pegmatite, and quartz, feldspar, mica, spodumene, beryl and columbite have been mined there at various times. The demand for sheet mica during World War II induced operators to work the long dormant mine in 1943 and 1944. Unwatering and underground mining permitted detailed studies of the geology by the writer in 1944 as part of the strategic-minerals investigations of the United States Geological Survey.

Although studies of some minerals in the pegmatite have been made by Boltwood (2), Brush and Dana (3, 4, 5, 6, 7), Comstock (10, 11), Hawes (13), Hillebrand (16), Penfield (19, 20), von Rath (24), Osborne (18), and Wright (25), no account of its internal structure or economic geology has been published. Brush and Dana commented on the paragenesis of the phosphates, but no paragenetic study of the pegmatite as a whole has previously been made.

The mine lies 550 feet N. 48° E. of the railroad station in Branchville. To reach the village from White Plains, New York, travel 22 miles eastward on the Merritt Parkway to route U. S. 7, then proceed 9 miles northward on route 7 to Branchville. The railroad station lies on the eastern side of the highway, on the Housatonic Branch of the New York, New Haven and Hartford Railroad.

* Published by permission of the Director, U. S. Geological Survey.

The first excavation in the pegmatite was made about 1876 by A. N. Fillow, then owner of the property. He is reported to have mined mica. The mica recovered was then considered of inferior quality, and operations ceased sometime before the spring of 1878. At that time, George J. Brush and Edward S. Dana, both of Yale University, became so enthused about the new minerals at Branchville that they engaged Fillow to excavate the deposit with funds furnished by Yale. In 1880 the Union Porcelain Works of Greenpoint, New York, bought the property and operated it for feldspar and quartz until at least 1890. The Bridgeport Wood Finishing Company of Bridgeport, Connecticut, is said to have operated for quartz and feldspar prior to 1920. From September 1943 to November 1944, Fred and Joseph Burrone and Carlo Rusconi, all of North Branford, Connecticut, operated the mine for mica, and the Sandy Ridge Mica and Mining Company, Inc., 927 15th Street N. W., Washington, D. C., worked the mine in November and December 1944.

The main working is an open cut 240 feet long, 50 to 85 feet wide and 60 feet in maximum depth. A crosscut 20 feet long has been driven into the northern wall of the cut. From the crosscut one drift extends 75 feet northwest, and another 57 feet southeast. Both open cut and drifts are partly backfilled.

ACKNOWLEDGMENTS

Before the final draft of this paper could be prepared the writer was called abroad, and his friend, Eugene N. Cameron, Commodity Geologist for Industrial Minerals, U. S. Geological Survey, therefore assumed the task of editing and revising the paper. The writer is deeply indebted to Dr. Cameron for this favor and also to Prof. Andrew H. McNair, Dartmouth College, for his appreciated criticisms. Drs. George Switzer and Harold Mikami, Yale University, generously rendered valuable assistance in identifying minerals collected by the writer. Special thanks are due to Prof. Glenn W. Stewart, University of New Hampshire, for his aid in determining refractive indices of feldspar, and to Benjamin Levin, U. S. Bureau of Mines, who gave valuable advice during the field work. Frederic Main and Karl Adams, U. S. Geological Survey, aided in mapping, and the operators of the Branchville mine also cooperated generously and wholeheartedly.

STRUCTURE AND COUNTRY ROCK

The pegmatite appears to be tabular, but only its hanging wall is exposed (Fig. 1). It is at least 200 feet long and at least 40 feet thick. The hanging wall strikes north 60 degrees west and has an average dip of 45 degrees northeast. Two features suggest that the body either plunges

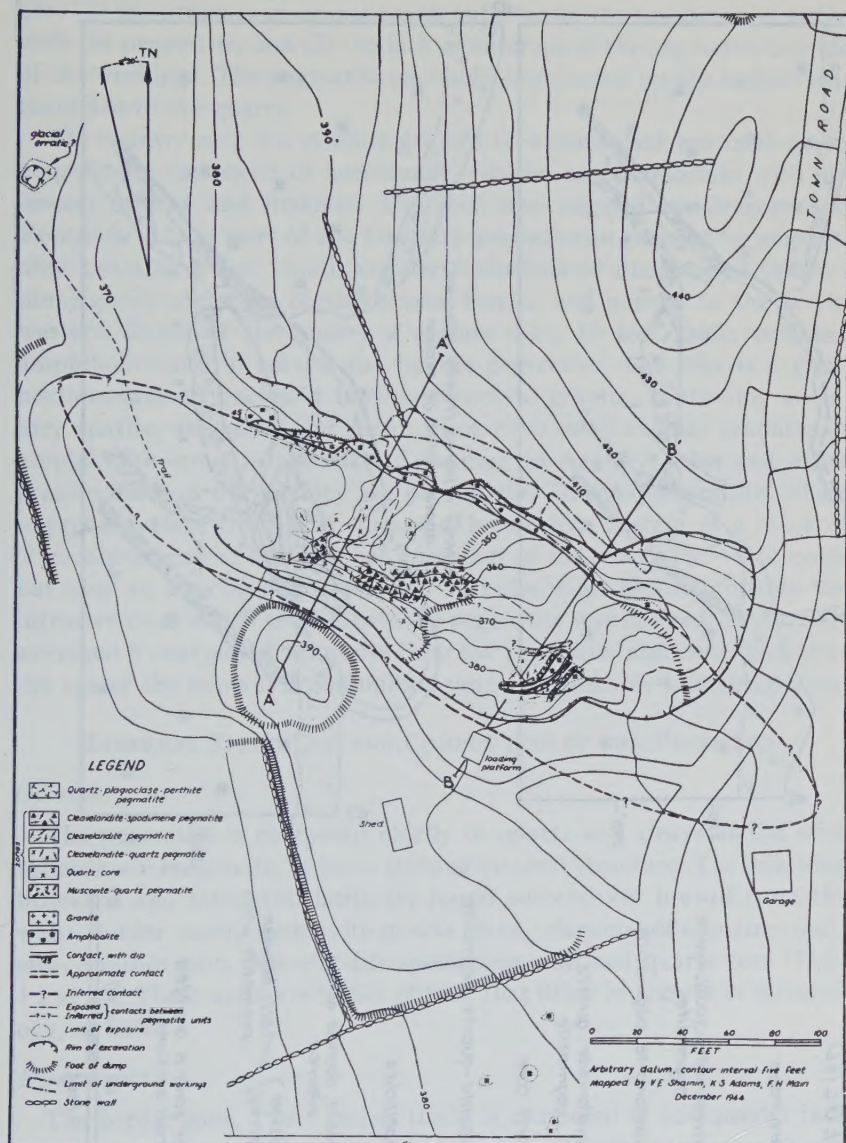


FIG. 1. Geologic map of the Branchville Mica Mine, Redding, Connecticut.

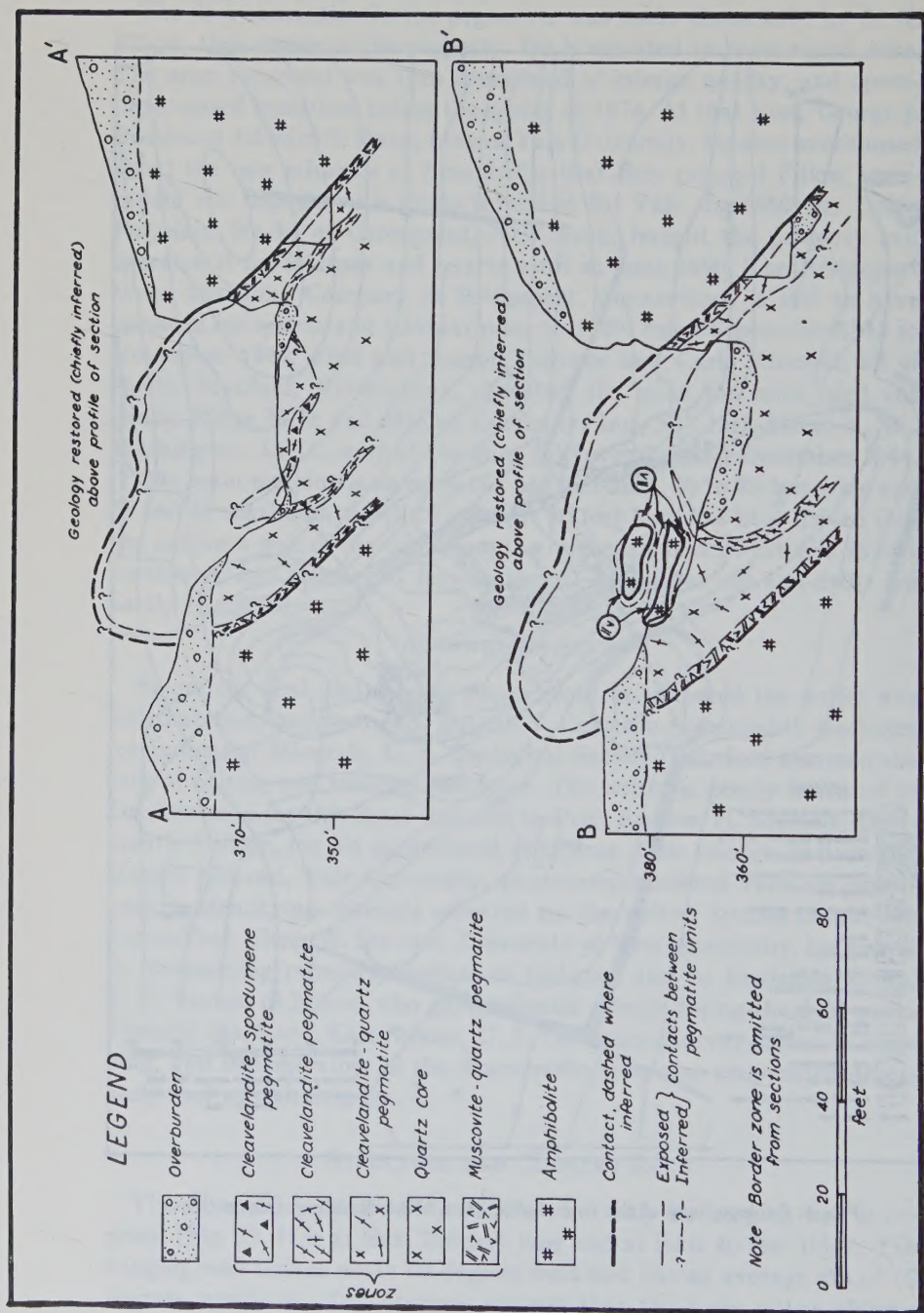


FIG. 2. Structure sections, Branchville Mica Mine, Redding, Connecticut.

beneath country rock in both directions along strike or terminates. These are: (1) the presence of country rock outcrops to the southeast on strike with the pegmatite, and (2) the lack of outcrops of the pegmatite outside of the workings. The pegmatite probably terminated up dip a short distance above the quarry.

The country rock is a medium-grained (2–4 mm.) dark brownish-green amphibolite composed of hornblende, biotite, and plagioclase with accessory sphene and ilmenite. The rock was mapped by Gregory and Robinson (12) as part of the Danbury granodiorite gneiss. The amphibolite contains a few small, angular inclusions of fine-grained (0.2–0.3 mm.) gneiss composed of plagioclase, biotite, and quartz. In the northwestern corner of the quarry a granite dike, 10 feet thick, cuts the amphibolite and in turn is cut by the pegmatite. The dike is a gray, medium-grained gneissoid biotite-muscovite granite, containing accessory apatite, magnetite and zircon. Numerous small angular xenoliths of amphibolite occur in the dike. According to Agar (1), this and other granite dikes in the vicinity are part of the Thomaston granite, which is probably late Ordovician in age. The western margin of a stock of Thomaston granite lies 500 feet northeast of the mine. The stock crops out over an area $3\frac{1}{2}$ miles long and $1\frac{1}{2}$ miles wide, and is probably the intrusive from which the Branchville pegmatite was derived. Shaub (23) averaged 5 analyses of uraninite from the pegmatite and concluded that the age of the mineral is 368 million years, or probably late Ordovician.

INTERNAL STRUCTURE AND COMPOSITION OF THE PEGMATITE

General

The pegmatite is composed chiefly of quartz and cleavelandite with subordinate muscovite. It has a striking internal structure. The following lithologic and structural units are found successively inward from the wall: border zone, muscovite-quartz zone, cleavelandite-quartz unit, cleavelandite unit, cleavelandite-spodumene unit and quartz core (Figs. 1 and 2).¹ These units are bodies of rock that differ in texture or mineralogy, or both.

Border zone

The border zone, 2 to 6 inches thick, is composed of one-quarter inch grains of quartz and oligoclase (*An* 14) with subordinate muscovite and accessory green apatite, green tourmaline, hornblende, and biotite. Calcite is a minor constituent. In some places the zone consists largely of

¹ The classification of pegmatite units followed is that developed jointly by geologists of the Federal Survey engaged in investigations of domestic pegmatites during the war.

quartz, and oligoclase is lacking; in others oligoclase is the only essential mineral. Hornblende and biotite occur in the upper part of the zone and are visible only in thin section. They were probably derived from the amphibolite. Calcite occurs in narrow veins, commonly along the contact with amphibolite.

Muscovite-quartz zone

The muscovite-quartz zone (or wall zone) is 1 to 2½ feet thick. Its average thickness is 1½ feet. It is composed of muscovite, quartz, and cleavelandite (*An* 5-6) with minor apatite, pyrite, tourmaline and fluorite.

Muscovite constitutes 30-60% of the zone and occurs in deep rum-colored books oriented with cleavage roughly perpendicular to the hang-

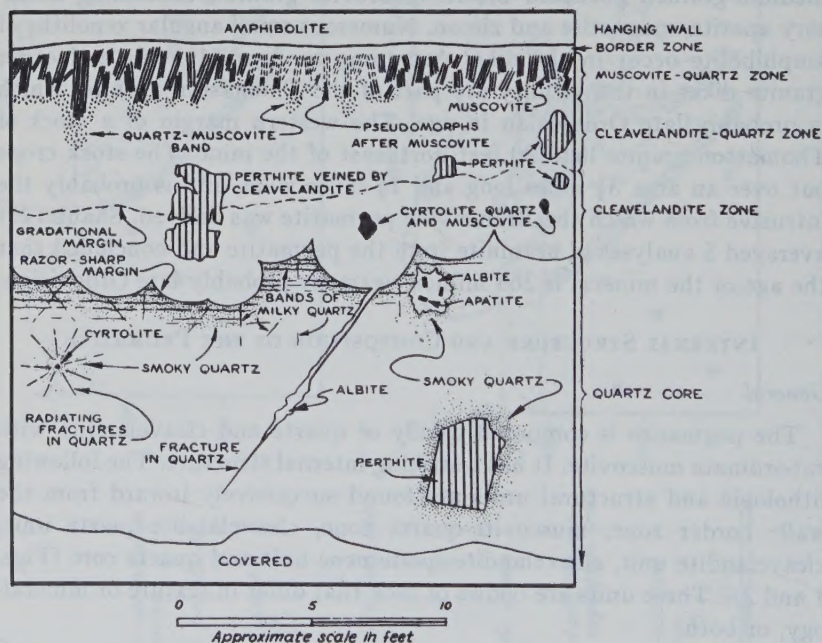


FIG. 3. Composite sketch of northeastern quarry face showing mutual relations between minerals and zones. Scale of small features is slightly exaggerated.

ing wall (Fig. 3). The books, easily broken from their matrix, range from 1 to 24 inches in diameter and $\frac{1}{8}$ to 12 inches in thickness. Most of the books are 5 inches in diameter and 1 inch thick. Ruling is a common defect. Cross-fracturing, A-structure and reeving are present in some books. Most of the mica is hard and free-splitting.

Approximately 15 percent of the muscovite visible in the wall zone in December 1944 had been replaced by material that is too fine-grained to identify in thin section, but which appears to be albite (An ca. 5) and quartz. Perfect pseudomorphs after muscovite have been formed. The replacement has been limited to five parts of the zone. The three largest parts occur in the eastern third of the workings, and are irregular in outline. Their distribution does not appear to be influenced by structural or mineralogical control. Within them practically all of the muscovite adjacent to the wallrock contact, including that in the border zone, has been replaced. Most of the mica in the lower $\frac{1}{3}$ or $\frac{1}{4}$ of the wall zone is unaffected by replacement. Large books, occupying the full thickness of the zone, grade from unaltered muscovite in the lower part to pseudomorphs in the upper part of the zone (Fig. 3). The margin between replaced and unreplaced portions of a single book is gradational over not more than $\frac{1}{4}$ inch. In thin section, small, scattered remnants of muscovite are visible in the replaced portions. It seems likely that replacement of muscovite began at the wallrock contact and advanced toward the center of the pegmatite.

Although the footwall of the pegmatite is not visible, the wall zone may be developed along it. The evidence for this is found around two large bodies of amphibolite that are probably xenoliths in the pegmatite (section $B-B'$). The border and wall zones of the pegmatite surround each of the bodies. Studies by the writer of other pegmatites in Connecticut (Toll Gate mine, Middletown; Cramer mine, Portland; Gotta-Walden mine, Portland) have suggested that a xenolith bounded on its lower surface by a wall zone may indicate the presence of a similar zone on the hanging wall of the pegmatite. Likewise (as in the Cramer mine) a xenolith bounded on both surfaces by a wall zone may indicate the presence of that zone along both walls of the pegmatite. At Branchville, the mica-bearing wall zone is present on both upper and lower surfaces of the amphibolite bodies. It is believed likely, therefore, that the zone is present adjacent to the unexposed footwall.

Cleavelandite-quartz unit

The cleavelandite-quartz unit has an average thickness of three feet, and is composed of cleavelandite and quartz with subordinate muscovite. Minor constituents are perthite and garnet.

Cleavelandite is commonly white, fine-grained (laths $\frac{1}{8}$ – $\frac{1}{4}$ inch long), and compact. Muscovite occurs in pale-green books $\frac{1}{2}$ –1 inch in diameter. Concentrically curved books are rare in this unit, although they are common in the cleavelandite unit. Perthite occurs in scattered anhedral crystals, 1 to 5 feet long, that vary from grayish-white to light buff-

brown. One crystal, 3 feet long, is partly in the cleavelandite-quartz unit and partly in the cleavelandite unit. The crystal is veined throughout its length by minerals of both zones (cleavelandite, quartz, garnet and muscovite) (Fig. 3). This, and other crystals of microcline-perthite in the cleavelandite-quartz unit and cleavelandite unit, appear to be unreplaced parts of a pre-existing microcline-perthite zone.

Cavities, $\frac{1}{2}$ to 4 inches in diameter, occur in the zone. Superposition of one mineral on the crystal faces of another is common in these cavities. Albite ($An\ 2-3$) is found in most of the cavities and commonly forms the lining on which the following minerals have grown, in the order listed: perthite, quartz, muscovite, apatite, calcite, and pyrite. Perthite occurs in reddish pink subhedra $\frac{1}{4}$ inch long. Albite is a very minor constituent in these crystals compared with the coarser perthite mentioned above. Apatite, in colorless, white, pale-yellow, or purple prisms, occurs on crystals of all the other minerals, but its crystal faces rarely support other minerals. Small euhedral crystals of albite and green muscovite are often partially embedded in quartz crystal faces, indicating an overlapping sequence of crystallization.

Cleavelandite unit

The cleavelandite unit is a discontinuous body lying along the core of the pegmatite. For the most part it ranges from 2 to $2\frac{1}{2}$ feet in thickness,

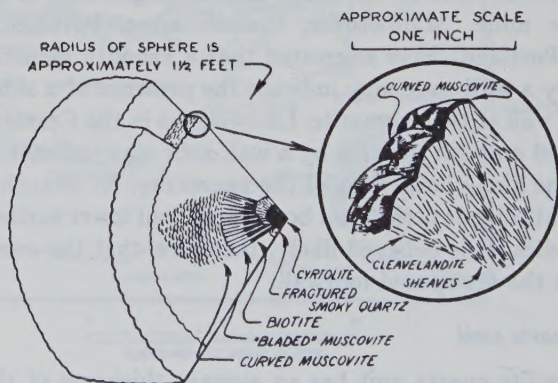


FIG. 4. Sketch of section through a hemisphere in the cleavelandite zone. Inset in circle is an enlargement showing the relation between cleavelandite sheaves and books of curved muscovite.

and is composed of cleavelandite, with subordinate muscovite, cyrtolite, quartz, and biotite. Apatite, garnet, perthite, columbite-tantalite, and other minerals are minor constituents. The unit has an unusual structure. It consists of laterally coalescing hemispheres that commonly have

a radius of 1 to $1\frac{1}{2}$ feet. The outer margin of the unit grades indistinctly into the cleavelandite-quartz unit and the inner margin has a very sharp contact with the quartz core.

Each hemisphere in the unit may be considered as a separate structural element (Fig. 4). Four minerals occur invariably in a regular succession. One or more of these minerals may be absent in a given hemisphere, but if so, the order of the others does not change. Commonly at the center of the hemisphere is a brown crystalline aggregate of cyrtolite 1 inch in diameter that shows numerous tetragonal pyramids with curved faces. In some hemispheres small masses of smoky quartz, 1 to 6 inches in diameter, lie adjacent to one or more sides of the cyrtolite aggregate. The quartz is invariably shattered by fractures radiating outward from the cyrtolite. In a few hemispheres, the nucleus is a mass of light-smoky quartz, 1 to 4 inches long, which is a component part of the cleavelandite-quartz zone. Outside the quartz lies brown biotite, usually in narrow blades ($\frac{1}{2}$ to 1 inch long) in which the cleavage is parallel to radii of the hemisphere. The biotite passes outward into similarly oriented blades of greenish muscovite ($\frac{1}{2}$ to 3 inches long).

Outside the muscovite blades are concentrically curved muscovite books whose cleavage is subparallel to the surface of the hemisphere. The innermost curved books are often less than 3 mm. in diameter; they gradually increase in size toward the surface of the hemisphere, where they are usually $\frac{1}{2}$ to 1 inch broad. The transition from bladed to curved books is sharp and distinct.

Biotite and both types of muscovite, in most cases, have the form of a cigar-shaped body whose long axis is parallel to a radius of the hemisphere (Fig. 4). The curved muscovite at the distal termination of such a cigar-shaped body, may or may not lie on the surface of the hemisphere. Often the curved books form unbroken spherical shells separated from one another by thicker intervening shells of cleavelandite.

Cleavelandite in the hemispheres occurs in fine-grained white laths, often curved, which are always grouped in radiating sheaves, commonly 1 inch in length. The rounded upper surface of each sheaf is commonly smooth and hemispherical. In the ideal case the sheaves are oriented with their curved surfaces tangent to the surface of the main hemisphere of which they are a part. The lateral coalescence of hundreds of these small sheaves forms the main hemisphere, the surface of which has an uneven, cobblestone-like appearance. The curvature of the muscovite conforms to the rounded tops of the cleavelandite sheaves, and in simple cases, each book lies on the curved surface of a sheaf (Fig. 4). This strongly suggests that the muscovite is either contemporaneous with or later than the cleavelandite. In the aggregates of curved muscovite form-

ing part of the cigar-shaped bodies mentioned above, the books lie on top of one another and their basal cleavages are nearly parallel. The first books to form may have been contemporaneous with formation of the sheaves, or they may have formed by replacement of the rounded surfaces of the sheaves. Later in the sequence muscovite may have replaced the remaining cleavelandite and the curvature of these books may have been inherited from the adjoining, previously formed books.

Cleavelandite-spodumene unit

The cleavelandite-spodumene unit is exposed only in the southwestern corner of the open cut where it is probably 2 to 6 feet thick (Figs. 1 and 2). Owing to lack of exposures, much of its structure as shown in the figures is inferred. It lies adjacent to the core and in general seems to be limited to the crest of the core. The unit is composed of cleavelandite with subordinate spodumene, muscovite and quartz. Minor constituents are: eucryptite, garnet, microcline-perthite, columbite-tantalite, lithiophilite, manganoan apatite, and other minerals. The following minerals, not found in the unit by the writer, but present in the Yale Systematic Collection, Yale Peabody Museum or described by Schairer (22) and by Brush and Dana (3, 4, 7) were probably collected from the unit: rhodochrosite, amblygonite, purpurite, reddingite, dickinsonite, fairfieldite, natrophilite, eosphorite, triploidite, fillowite, triplite, hureaulite, and chabazite. Beryl was not observed in the pegmatite, although it occurs on the dump and as specimens in many museums. Most of the specimens are aggregates of columnar green prisms, and some are two feet long. One specimen of beryl (Peabody Museum, No. 8261) is associated with cleavelandite sheaves growing outward from a spodumene crystal, suggesting its occurrence in the cleavelandite-spodumene unit.

Spodumene occurs in scattered crystals in a matrix of cleavelandite and forms subhedral prisms, flattened parallel to $a\{100\}$. The prisms average 1 foot long, 6 inches wide and $\frac{3}{4}$ inch thick. About 40 per cent is unaltered and the remainder is altered in various degrees. The alteration products have been described in detail by Brush and Dana (6). Those least altered have been replaced, in part, by very fine-grained albite and eucryptite. Further alteration results in the formation of "cymatolite," a mixture of fine-grained albite and muscovite. Microcline pseudomorphs after spodumene were also found by Brush and Dana.

Muscovite also occurs in the cleavelandite-spodumene unit in small hemispherically curved books ($\frac{1}{4}$ to 2 inches in diameter) in unusually homogeneous bodies consisting of muscovite with subordinate cleavelandite, quartz, perthite, and accessory garnet and columbite-tantalite. The bodies appear to be irregular and attain a maximum length of 30 feet.

The manganese phosphates, of which lithiophilite is the most common, occur in rare, scattered concentrations within the cleavelandite-spodumene unit. Yellowish-brown lithiophilite occurs in isolated, ellipsoidal nodules from $\frac{1}{4}$ inch to more than one foot long; their average length is 3 inches. The nodules are invariably coated with bluish-black manganese oxide. In some specimens, lithiophilite veins cut spodumene indicating later crystallization of the phosphate. Numerous veins of cleavelandite cutting lithiophilite indicate that the silicate continued to form after the phosphate.

Quartz core

The core of the pegmatite is poorly exposed but probably ranges from 20 to 35 feet thick (Figs. 1 and 2). Only its upper contact is exposed. It is irregular though sharply defined. Coarsely crystalline quartz comprises well over 95 per cent of the visible core. Minor constituents are, in order of abundance: spodumene, albite, perthite, apatite, cyrtolite, muscovite and garnet. The quartz is predominantly milky but smoky quartz occurs in a 6-inch to 1-foot band adjacent to the cleavelandite unit in some places. Smoky quartz also occurs in halos, 8 to 12 inches wide, surrounding some crystals of perthite, cyrtolite and masses of albite.

Thin bands or layers of milky quartz ($\frac{1}{2}$ to 3 mm. thick) occur in the core (Fig. 3). In thin section each layer is seen to contain numerous irregular fluid inclusions from 0.0003 to 0.02 mm. in diameter. Their average size is 0.006 mm. Most of the layers are subparallel to the hanging wall of the pegmatite. They are especially conspicuous adjacent to the upper margin of the core where they occur in a matrix of smoky quartz. There the layers terminate unconformably against the cleavelandite hemispheres (Fig. 3). The origin of the layers is unknown, but they appear to antedate formation of the cleavelandite unit. Spodumene occurs as diversely oriented, isolated crystals, similar in habit and size to those described in the cleavelandite-spodumene unit. One or both sides of many crystals are covered by a 1-inch layer of white cleavelandite plates arranged in sheaves radiating outward from the spodumene. The crystals appear to occur only within a few feet of the margins of the core.

Cleavelandite occurs in the core as irregular aggregates of small subhedral crystals and as veins $\frac{1}{8}$ to $\frac{1}{4}$ inch wide and up to 6 feet long. The veins are composed of very fine-grained, dense cleavelandite, which fills fractures and locally replaces the walls of the fractures. One vein was observed to be in contact with, and blend into, the cleavelandite unit. A very few subhedral crystals of perthite, 3 to 4 feet in length, occur within 10 feet of the core's margins. Apatite occurs in dark greenish-blue subhedra 1 inch long in the masses of cleavelandite mentioned above.

Crystalline cyrtolite aggregates in the core, similar to those in the cleavelandite unit, are completely surrounded by a halo of smoky quartz, usually 2 feet in diameter. Conspicuous fractures in the quartz radiate outward in all directions from the cyrtolite nucleus. The zone of fracturing coincides roughly with the extent of the halo. A similar occurrence has been described by Landes (17) from the Baringer Hill, Texas, pegmatite where rare earths occur in massive quartz which is radially shattered, forming so-called "stars" 8 to 10 feet in diameter. Hidden (15) found that the "stars" at Baringer Hill served as clues to rare minerals at their center. Hess and Wells (14) believed that the growth of the nuclear mineral "took place faster than the older mineral is replaced, breaking the rock radially," and Landes has concurred in this opinion.

ORIGIN OF THE PEGMATITE

General

Three stages in the formation of the pegmatite are postulated: a first stage during which the zones developed; a second stage marked by partial replacement of the zones; and a third stage of supergene alteration. There is no evidence at Branchville to indicate the order in which the border zone, muscovite-quartz zone, microcline-perthite zone and quartz core formed. However, their relationships to the cleavelandite-quartz, cleavelandite, and cleavelandite-spodumene units indicate that the zones developed at an earlier stage, and as there is no evidence that the zones were developed at the expense of pre-existing massive pegmatite, zone development appears to represent the first stage in the development of the pegmatite as a whole. During the first stage, there may have been limited replacement of earlier formed minerals by those later in the sequence. Near the end of, or after, the first stage, the evidence suggests that hydrothermal solutions altered the zones, particularly those with abundant minerals, such as perthite, susceptible to replacement. New units were developed along the contacts between the zones because the zones provided favorable loci. Some solutions followed the wall rock contact of the pegmatite and replaced parts of the border and wall zones. The third stage consisted of supergene alteration of previously formed minerals by circulating ground water.

In both first and second stages, plagioclase grew progressively more sodic. Indices of refraction, determined by the single variation method, indicate anorthite contents as follows: border zone, $An\ 14$; muscovite-quartz zone, $An\ 5-6$; cleavelandite-quartz unit, $An\ 3$; cleavelandite unit, $An\ 3$; subhedra in cavities in the cleavelandite-quartz unit, $An\ 2-3$. There was no detectable difference between specimens from the same zone or unit collected over a distance of almost 200 feet along strike.

First stage

In the first stage, the border zone, muscovite-quartz zone, microcline-perthite zone and quartz core were formed. From analogy to other New England pegmatites (8) it seems likely that the order of the zones from the walls inward is likewise the order in which they were deposited, but no positive evidence of this has been found at Branchville. The microcline-perthite zone has been almost completely obliterated by hydrothermal replacement. Microcline-perthite anhedral, which occur throughout the cleavelandite and cleavelandite-quartz units, are clearly veined by cleavelandite, quartz, muscovite and garnet. This indicates the presence in both units of microcline-perthite earlier in age than the most abundant constituents of the units. A microcline-perthite zone—of the kind postulated at Branchville—surrounding a quartz, or quartz-rich core is a common feature in other New England pegmatites that have suffered little or no hydrothermal replacement (9, 21).

Although the present visible margin of the core is exceedingly sharp and well defined (as a result of the replacement postulated below), the original boundary between the microcline-perthite zone and the core was probably similar to that in other New England pegmatites (9), possessing cores of primary origin. The margins are commonly gradational in that some feldspar subhedra project into the core or lie wholly within the core near its margins, but it is also sharp with respect to the contacts between individual feldspar crystal faces and the quartz (Fig. 5). This distinction is vital to an appreciation of the influence exerted by the margin of the core over the passage of later solutions.

Second stage

The second stage appears to have been complex. Two phases are discernible: an early phase during which the bulk of replacement occurred, and a late phase during which cavity fillings were deposited. The cleavelandite-quartz, cleavelandite, and cleavelandite-spodumene units formed during the second stage. The sequence of formation is not known. The chief loci of replacement were the perthite zone and the margin of the core. By far the most abundant mineral formed in this stage was cleavelandite. Quartz, muscovite, garnet, spodumene, the manganese phosphates and many rare minerals also formed at this stage.

Many of the unusual structures of the cleavelandite unit are best explained by replacement in this stage. The formation, in the core, of cyrtolite aggregates which radially shattered the surrounding quartz, apparently preceded formation of the cleavelandite unit. Sharp boundaries between crystal faces of perthite subhedra (on the inner margin of the perthite zone) and quartz of the core are believed to have provided

passageways for hydrothermal solutions rich in soda and silica. Aided by the radial fractures these solutions gained access to cyrtolite aggregates lying close to the core's margin, and biotite, muscovite and cleavelandite began to crystallize around the cyrtolite. It seems likely that the system

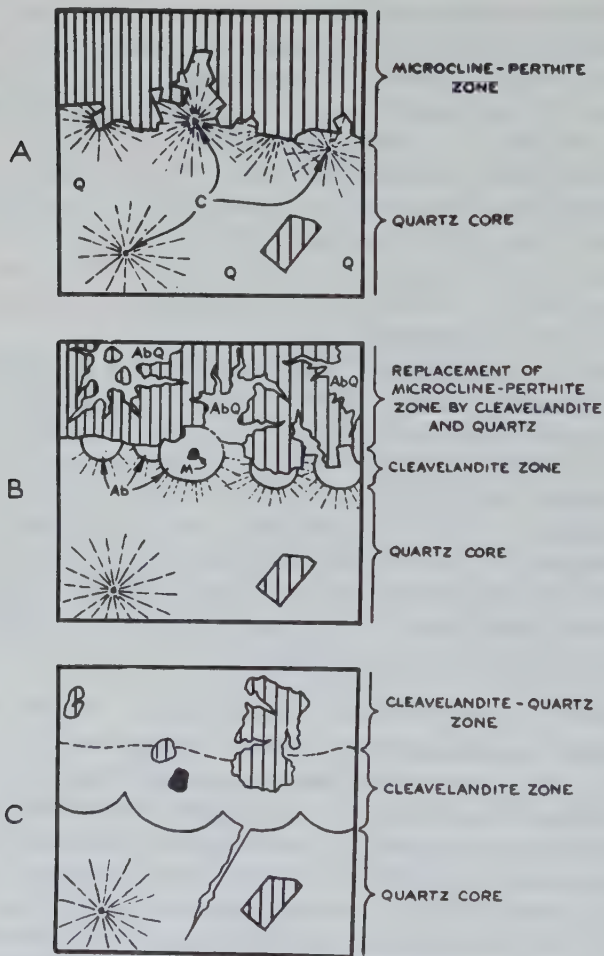


FIG. 5. Idealized sketches showing postulated origin of cleavelandite-quartz zone and cleavelandite zone. (Q=quartz; AbQ=cleavelandite and quartz; Ab=cleavelandite; M=aggregate of curved muscovite; C=cyrtolite surrounded by radiating fractures in quartz; shaded parts=predominant microcline-perthite.)

of radial fractures emanating from the cyrtolite was responsible for the spherical form assumed by the aggregate of newly formed minerals. Small bodies of radially shattered smoky quartz are sometimes present

adjacent to cyrtolite nuclei (Fig. 4) within the hemispheres. These quartz bodies appear to be unreplaced parts of the quartz core. The lateral coalescence of neighboring hemispheres gave rise to the cleavelandite unit. Probably contemporaneous with formation of the cleavelandite unit was the introduction of albite in the core as fracture fillings, replacement veins and isolated "unsupported" aggregates.

No evidence was observed to indicate the paragenetic sequence of most of the minerals of the cleavelandite-spodumene unit. Minerals of the late phase occur as crystals lining cavities. Carbonate and sulfide minerals are supported by the crystal faces of earlier minerals and were last to form in the cavities. Calcite veins in the border zone probably formed at this time.

Supergene alteration

Supergene alteration resulted in the formation of manganese oxide and purpurite from lithiophilite, and limonite from pyrite.

CONCLUSIONS

General

The Branchville pegmatite is a distinctly zoned body with a complex history. A first stage is recognizable in which the following zones formed, possibly from the walls inward by successive deposition: border zone, muscovite-quartz zone, perthite zone and quartz core. Replacement in a second stage altered the zones, and created new units along the contacts between the zones. The configuration of the units of the second stage therefore reflects the form and attitude of the zones because of the favorable loci provided by these pre-existing units. The cleavelandite-quartz unit, cleavelandite unit, and cleavelandite-spodumene unit are believed to have formed in the secondary stage. The third stage consisted of supergene alteration of previously formed minerals by circulating ground water.

There is no evidence to indicate termination of the sheet-mica bearing zone either down dip or along strike. However, a factor which should be studied with extreme caution in future operations for mica is replacement of muscovite in the zone. Whether or not the distribution of replaced portions is influenced by discernible geological factors needs determination. Studies to date have failed to reveal the presence of any controlling factor. It is anticipated that the quartz core continues as a virtually pure body down dip, and it is quite probable that several thousand tons of hand-separable quartz is available. There is no evidence to indicate the presence of a sizeable deposit of potash feldspar down the dip. However, if the crest of the core is present beneath deep backfill in the

southeastern end of the quarry, some feldspar may lie directly above the crest. Although a small reserve of spodumene is present in the pegmatite, a large percentage of the crystals are more or less altered. In addition, difficulty might be encountered in hand-cobbing spodumene crystals because of their small average size. It is unlikely that the pegmatite contains sufficient quantities of beryl, columbite-tantalite, uraninite and other rare minerals of economic importance to warrant commercial exploitation for them. However, one or more may be recovered as by-products from operations not centered on the wall zone.

Replacement deposits that transect zonal structure have been recognized before in pegmatites. However, the occurrence of replacement bodies, that do not, in general, transect earlier-formed zones has not been widely recognized. The evidence at Branchville suggests that such replacement bodies can easily be mistaken for zones unless carefully studied.

REFERENCES

1. AGAR, W. M., The granites and related intrusives of western Connecticut: *Am. Jour. Sci.*, **27**, 373 (1934).
2. BOLTWOOD, B. B., On the ultimate disintegration products of the radioactive elements: *Am. Jour. Sci.*, 4th ser., **23**, 78-88 (1907).
3. BRUSH, G. B., AND DANA, E. S., On a new and remarkable mineral locality in Fairfield County, Connecticut: *Am. Jour. Sci.*, 3d ser., **16**, 33-46 (1878).
4. BRUSH, G. B., AND DANA, E. S., On the mineral locality in Fairfield County, Connecticut, with description of two additional new species: *Am. Jour. Sci.*, 3d ser., **17**, 359-368 (1879).
5. BRUSH, G. B., AND DANA, E. S., On the mineral locality in Fairfield County, Connecticut: *Am. Jour. Sci.*, 3d ser., **18**, 45-50 (1879).
6. BRUSH, G. B., AND DANA, E. S., On the mineral locality at Branchville, Connecticut. Fourth paper. Spodumene and the results of its alteration: *Am. Jour. Sci.*, 3d ser., **20**, 257-284 (1880).
7. BRUSH, G. B., AND DANA, E. S., On the mineral locality at Branchville, Connecticut. Fifth paper: *Am. Jour. Sci.*, 3d ser., **39**, 201-216 (1890).
8. CAMERON, E. N., LARRABEE, D. M., MCNAIR, A. H., PAGE, J. J., SHAININ, V. E., AND STEWART, G. W., Structural and economic characteristics of New England mica deposits: *Econ. Geol.*, **40**, 369-393 (1945).
9. CAMERON, E. N., LARRABEE, D. M., MCNAIR, A. H., PAGE, J. J., SHAININ, V. E., AND STEWART, G. W., *U. S. Geol. Survey report on New England pegmatites*, in preparation.
10. COMSTOCK, W. J., Analyses of some American tantalates: *Am. Jour. Sci.*, 3d ser., **19**, 131-132 (1880).
11. COMSTOCK, W. J., On the chemical composition of the uraninite from Branchville, Connecticut: *Am. Jour. Sci.*, 3d ser., **19**, 220-222 (1880).
12. GREGORY, H. E., AND ROBINSON, H. H., Preliminary geological map of Connecticut: *Conn. Geol. and Nat. Hist. Survey, Bull.* **6**, 84 (1906).
13. HAWES, G. W., On liquid carbon dioxide in smoky quartz: *Am. Jour. Sci.*, 3d ser., **21**, 203-209 (1881).

14. HESS, F. L., AND WELLS, R. C., Samarskite from Petaca, N. M.: *Am. Jour. Sci.*, **19**, 21 (1930).
15. HIDDEN, W. E., Some results of late mineral research in Llano County, Texas: *Am. Jour. Sci.*, 4th ser., **19**, 427 (1905).
16. HILLEBRAND, W. F., On the occurrence of nitrogen in uraninite and on the composition of uraninite in general: *Am. Jour. Sci.*, 3d ser., **40**, 384-394 (1890). Also in *U. S. Geol. Survey Bull.* **78**, 64 (1891).
17. LANDES, K. K., The Baringer Hill, Texas, pegmatite: *Am. Mineral.*, **17**, no. 8, 381-390 (1932).
18. OSBORNE, T. B., The qualitative determination of niobium: *Am. Jour. Sci.*, 3d ser., **30**, 336 (1885).
19. PENFIELD, S. L., Analyses of two varieties of lithiophilite (manganese triphylite): *Am. Jour. Sci.*, 3d ser., **26**, 176 (1883).
20. PENFIELD, S. L., Effect of the mutual replacement of manganese and iron on the optical properties of lithiophilite and triphylite: *Am. Jour. Sci.*, 3d ser., **50**, 387-390 (1895).
21. SHAININ, V. E., Pegmatites of Topsham, Maine, report in preparation.
22. SCHAIRER, J. F., Minerals of Connecticut: *Connecticut Geol. and Nat. Hist. Survey, Bull.* **51**, 100, 101 (1931).
23. SHAUB, B. M., The occurrence, crystal habit, and composition of the uraninite from Ruggles Mine, near Grafton Center, New Hampshire: *Am. Mineral.*, **23**, no. 5, 339 (1938).
24. VON RATH, GERHARD, Mineralien aus den Vereinigten Staaten: *Niederrhein Ges. Bonn, Szb.* **42**, 56-62 (1885).
25. WRIGHT, A. W., On the gaseous substances contained in the smoky quartz of Branchville, Connecticut: *Am. Jour. Sci.*, 3d ser., **21**, 209-216 (1881).

CONSTRUCTION AND STUDY OF FLOW STRUCTURE MODELS FROM FIELD DATA

KURT E. LOWE, *196 Rockaway Parkway, Brooklyn 12, N. Y.*

ABSTRACT

Transparent models based on field data are helpful laboratory and training aids for the three-dimensional study of flow structures in igneous rocks. Field procedure is discussed and details of construction and assembly of models are given. An illustrative example involves the Storm King granite of the Hudson Highlands of New York.

INTRODUCTION

While investigating the Storm King granite in the Hudson Highlands of New York, the writer frequently encountered difficulties in determining the regional flow structures with sufficient accuracy in the field. Strong weathering effects limit reliable structural measurements to occasional road cuts exhibiting reasonably fresh rock surfaces. Hornblende crystals and crystal aggregates of rather stout prismatic habit, perhaps comparable to the shape of a matchbox, provide the visible linear elements arranged in both linear and planar flow structures. The resulting mineral parallelism has a streaky rather than banded appearance on the various exposure surfaces. But the streaks generally show insufficient variation in elongation, width and continuity to permit a clear distinction between lineation patterns representing traces of flow lines, flow layers and a combination of both. Also critical outcrop surfaces, e.g. perpendicular to flow lines or parallel to flow layers, are often absent or else poorly developed in the predominantly two-dimensional road cut exposures.

Consequently a method of constructing simple models based on all available field data was employed, to study the three-dimensional orientation of the flow structures in such doubtful localities.

FIELD PROCEDURE

A preliminary investigation is made to ascertain the reasonably constant orientation of visible mineral parallelism on exposure surfaces having similar strike and dip. This being the case, it can be assumed that the flow structures have sufficiently uniform orientation throughout the outcrop to permit study by the model method.

Measurements are then taken on as many different exposure surfaces as possible. A minimum of 8 to 10 is recommended. In road cuts much of the desired information must be obtained by careful study of relatively small re-entrant surfaces produced by blasting and quarrying. In addi-

tion to the strike and dip of each surface, the pitch¹ of lineation is determined.

The universal clinometer as described by Ingerson (1942) and Fairbairn (1942, p. 107) is a most useful instrument for this purpose. Otherwise pitch may be measured with the Brunton compass as follows: On high-angle surfaces the apparent pitch of lineation is found by sighting along the edge of the compass with the clinometer in a vertical plane striking parallel to the strike of the surface. On low-angle surfaces the bearing² of the lineation is measured by sighting with the compass held in the horizontal position. In both cases subsequent corrections have to be made, in order to find the pitch either stereographically (Bucher, 1944) or by adaptation of the diagram for computing apparent dip (Billings, 1942, p. 422).

Appearance of each surface should be noted in detail with the help of field sketches to indicate whether the mineral streaks are narrow or wide, short or long, continuous or discontinuous, linear or wavy, etc. Under favorable conditions actual scaling of these features may be useful. Finally fracture systems are measured with particular attention to presence and attitude of slickensides, frequency and spacing of joints within a system, mineralization of fractures and similar features.

CONSTRUCTION OF MODEL

Select a suitable vertical dimension for the model ($1\frac{1}{2}$ inches used by the writer) and prepare auxiliary construction scales as indicated in Fig. 1.

Construction of the model is greatly simplified by starting from a top horizontal plane whether or not field data for such a surface are available. The lines bounding this plane represent both the top edges of the model and the strike lines of the inclined surfaces. A preliminary layout of the ground plan is made on a Penfield protractor circle³ as shown in Fig. 2. The strikes of the outcrop surfaces are plotted in their correct orientation and numbered in consecutive order. Dips are indicated by map symbols. A ground plan layout of suitable proportions is obtained by proper grouping and parallel translation of the strike lines bounding the top horizontal plane. Surfaces inclined less than 90° are always represented as outside positive slopes, i.e. overhangs are avoided. This procedure of shifting surfaces parallel to themselves is proper, since field observations have indicated essential uniformity of mineral orientation.

¹ "The pitch is the angle that a line in a plane makes with a horizontal line in that plane." (Billings, 1942, p. 135.)

² "The bearing of a line in space is its projection onto the horizontal plane, measured from the geographical north." (Bucher, 1944, p. 195.)

³ Copies may be obtained from the University of Chicago Bookstore.

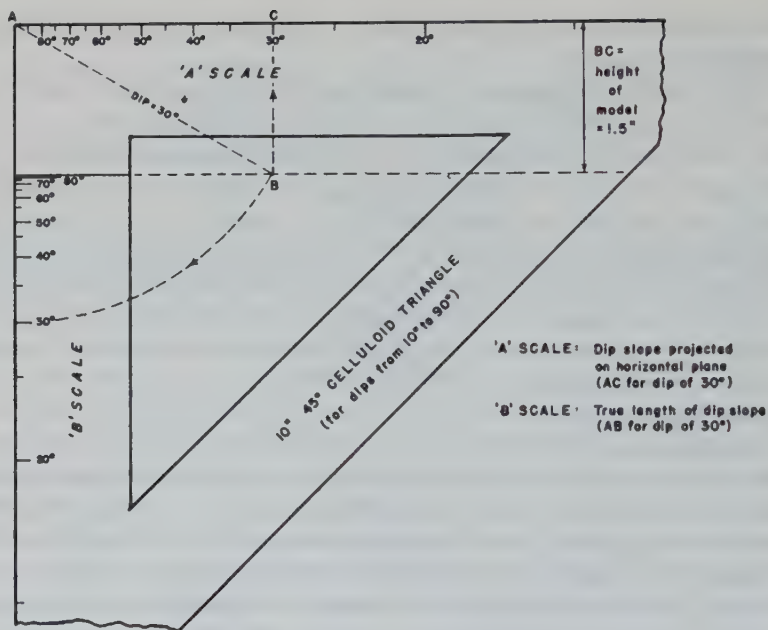


FIG. 1. Construction of auxiliary scales.

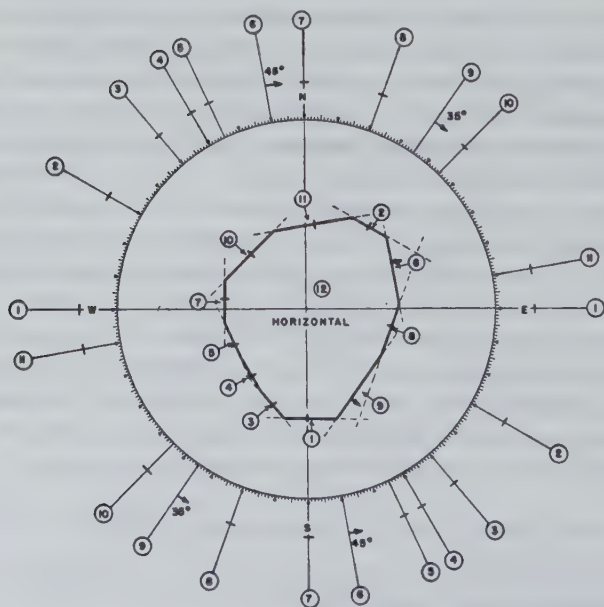


FIG. 2. Preliminary layout of ground plan for model shown in Figs. 5 and 7.

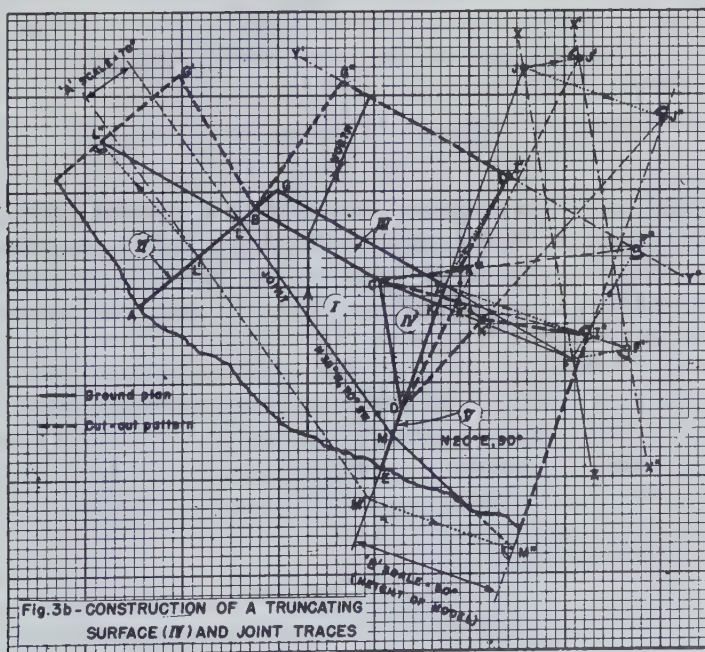
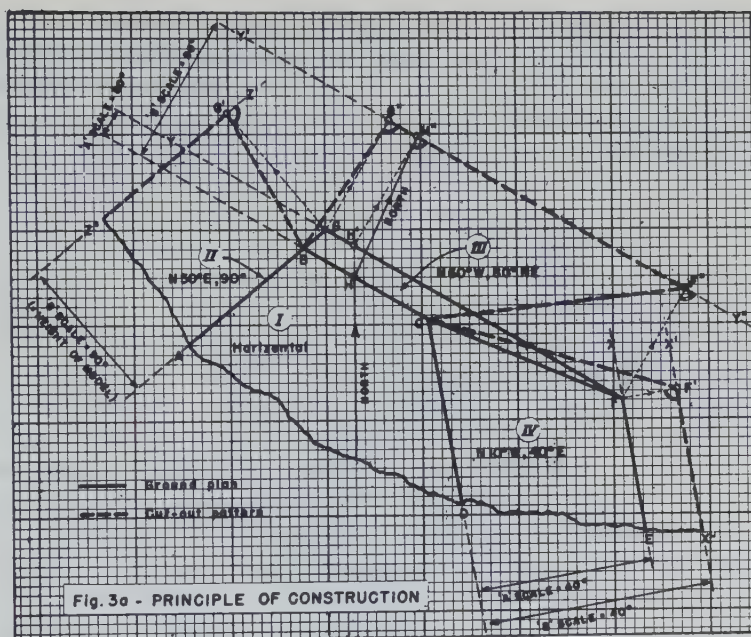


FIG. 3. Construction of model cut-out pattern. Modified portion of model shown in Fig. 5.

The actual construction of the model plan and net is made on a large sheet of 1/10 inch graph paper. Drafting operations may be speeded by the use of a parallel ruler and an aircraft plotter.⁴ Figures 3 and 4 illustrate successive steps of construction for a portion of the model shown in Figs. 5 and 7, with modifications designed to increase the instructive value.

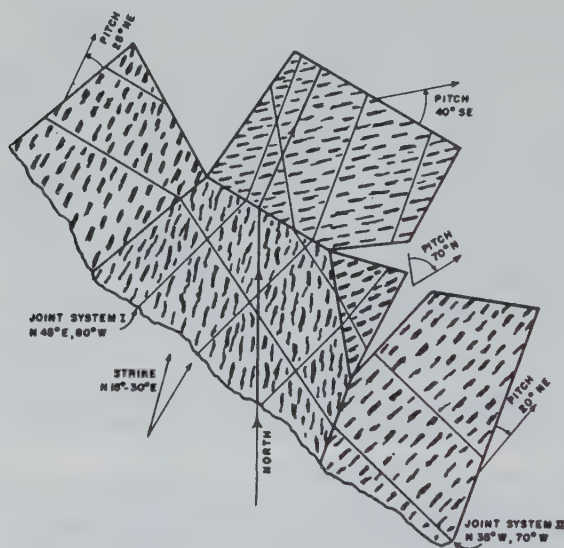


FIG. 4. Addition of surface lineations to tracing of cut-out pattern of Fig. 3b.

The top edges of the model are plotted first, maintaining the approximate proportions of the preliminary layout (Fig. 2). The ground plan is then completed by plotting the projected dips of the inclined surfaces from the auxiliary 'A' scale (Fig. 1) and by drawing the lines of intersection of these surfaces with each other and with the horizontal base plane of the model. Referring to Fig. 3a, lines AB, BC and CD are the top edges of surfaces II, III and IV respectively. The projection of surface III, dipping 80° NE, is obtained by drawing YF parallel to BC at a distance corresponding to 80° on the 'A' scale; likewise XE parallel to CD at a distance corresponding to the dip of 40° for surface IV. BG and CF are the vertical projections of the inclined edges formed by surfaces II-III and III-IV respectively.

⁴ Also known as Weems plotter, a combination protractor scale and straight edge permitting rapid and accurate plotting of bearings from a north reference line in a single operation (Weems, 1938, p. 52).

The next step involves rotation of each inclined surface about its strike axis (top edge) into the top horizontal plane, in order to obtain the net or cut-out pattern of the model (Fig. 3a). Using the auxiliary 'B' scale (Fig. 1) for the true lengths of the inclined model surfaces after rotation, draw another set of lines parallel to the top edges at distances corresponding to the surface dips, viz. $Z'Z''//AB$, $Y'Y''//BC$, $X'X''//CD$. The inclined edges are then rotated to complete the cut-out pattern. Each edge, appearing in vertical projection on the ground plan, is resolved into two cutting lines, because it is common to two adjoining surfaces each of which must be rotated about a different strike axis. Edge CF, formed by surfaces III and IV, is first rotated about BC and then about CD. Point C lies in the top horizontal plane and therefore remains in position during rotation. Point F, the intersection of edge CF with the horizontal base plane of the model, is rotated about BC by erecting a perpendicular to $Y'Y''$ (base line of surface III and parallel to BC) and finding the point of intersection F'' . Similarly F' is determined by rotation of F about CD. CF' and CF'' are the desired cutting lines of edge CF and must be of equal length. This provides a useful check on the accuracy of construction. Lines BG' and BG'' are constructed in the same manner by rotating point G about AB and BC.

To provide a means of orienting the model, the traces of a vertical NS plane approximately bisecting the ground plan should be plotted. HH' (Fig. 3a), for instance, is the trace of this reference plane on surface III as it appears on the ground plan. HH'' is the actual trace on the cut-out pattern.

When field data are obtained from a road cut, vertical or high-angle surfaces will predominate with the effect of reducing the size of model surfaces with medium to low dips to triangular facets truncating the top corners of the model. Although the basic principle of construction has been demonstrated above, it might be appropriate to discuss its application to the specific case involving a truncating surface of this type (Fig. 3b).

By adding the vertical surface V (Fig. 3b) to the layout of Fig. 3a, surface IV becomes a small triangular truncation of the corner formed by surfaces I, III and V. DJ (edge between IV and V) and its intersection K with edge CF are found by the same method of construction used in Fig. 3a. The revised ground plan, then, shows three new edges, viz. CK (truncated portion of CF), DK (truncated portion of DJ) and KI (edge between III and V). DJ is rotated about CD and DE to obtain the cutting lines DJ' and DJ'' . CF' and DJ' , both the result of rotation about CD, intersect in K' thus defining CDK' as the true outlines of surface IV. Describe an arc of radius CK' about C to intersect CF'' in

point K''' . Then $CK' = CK''' =$ two cutting lines of edge CK . Likewise $DK' = DK'' =$ cutting lines of edge DK . Finally locate I' by rotation of I (terminus of edge KI in base plane of model) about BC and I'' by rotating about DE . Connect K''' with I' and K'' with I'' to complete the revised cut-out pattern.

Fracture systems, dikes, etc., may now be added by finding their traces or lines of intersection with the surfaces involved. Fig. 3*b* shows the construction of a joint cutting surfaces I , II and V . LM is the trace on surface I and $L'M'/LM$ the vertical projection of the dip slope (' A' ' scale = 70°) toward the SW. Consequently LL' and MM' are the ground plan projections of the joint traces on surfaces II and V respectively. L' is rotated about AB to L'' , and LL'' is drawn to show the actual trace on the cut-out pattern. MM'' is the corresponding trace on surface V .

Mineral lineation is the last structural feature placed on the construction net by plotting its pitch on each surface of the cut-out pattern, and by indicating its orientation with a series of parallel guide lines (not shown in Figs. 3*b* and 4).

The outlines of the cut-out pattern together with north reference line, joint traces, dikes, etc., are now traced in India ink on an overlay of 15-point (.015 inch thick) transparent cellulose acetate, the material used to fashion the model. It is advisable to dull the glossy acetate surface by vigorous rubbing with talcum powder, Fuller's earth or a similar mild abrasive, in order to improve its ink-adhesion quality. Tracing paper or tracing cloth are suitable substitutes for the acetate, but must subsequently be mounted on thin cardboard to lend adequate rigidity. The obvious drawback of this procedure is the lack of transparency of the resulting model.

The actual appearance of mineral lineation on the original outcrop surfaces is reproduced in ink directly on the acetate overlay by referring to the field sketches and by following the guide lines of pitch (Fig. 4). India ink, black or colored, is preferable to special acetate inks, because corrections and changes can be made readily on the completed overlay. India ink does not form a permanent bond with the acetate and can be removed with a little absorbent cotton wrapped tightly around the tapering end of a brush or pen holder and moistened with water containing a small amount of ammonia.

Upon cutting out and folding of the acetate model pattern, the cut edges of the inclined surfaces will join properly, if reasonable care has been exercised in its construction. Folding of the model pattern is facilitated by making shallow scratches on the *inside* surface of the acetate

along the folding lines. The rather brittle material also has a tendency to crack or split along sharp bends no matter how carefully the operation is performed. This drawback is overcome by the bonding procedure shown in Fig. 6.

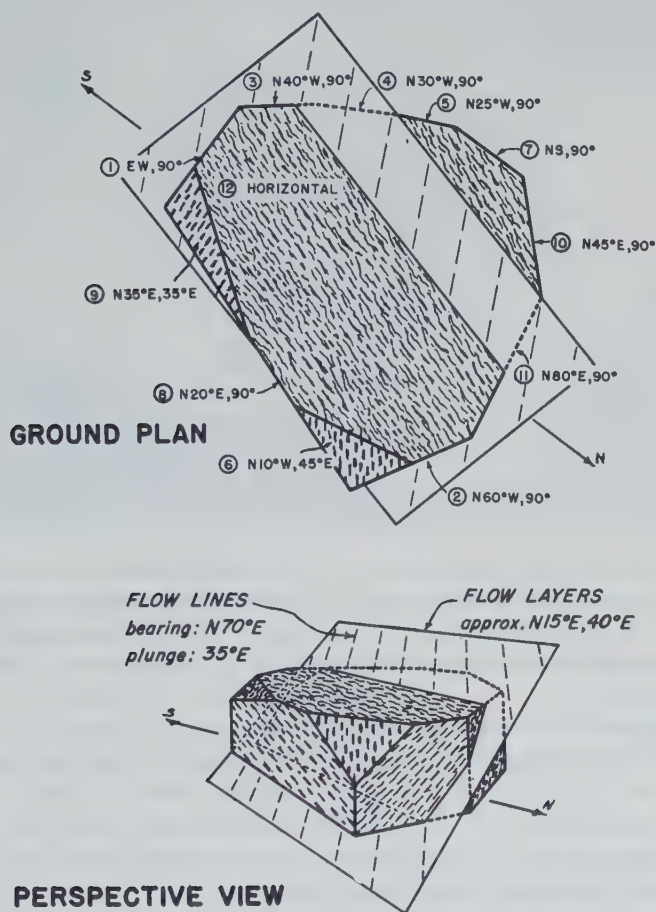


FIG. 5. Model showing flow structures in road cut of Storm King granite at Lake Askoti, 7 miles SW. of Bear Mountain, N. Y. Joint traces and pegmatite dike are omitted. Numbers of outcrop surfaces correspond to Fig. 2.

Hold the free or split edges of the model firmly together and place a dry, L-shaped strip of acetate across the juncture on the inside of the model. Dip a brush into ethyl acetate (or acetone) and apply to the free

edges of the strip. Capillary action will draw the liquid into the space between the strip and the model surface where it will dry in a matter of seconds. The resultant bond is durable and transparent serving at the same time as reinforcement of the model edge. Transparent scotch tape is not recommended for this purpose, because it will become wrinkled and discolored with time.

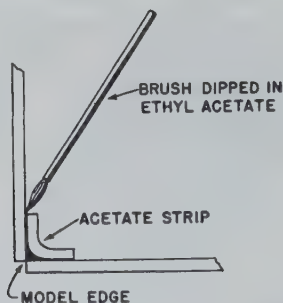


FIG. 6. Method of bonding and reinforcing the model edges.

STUDY OF THE MODEL

Orientation of the transparent model on a baseboard containing suitable directional markings (Fig. 7) reveals the three-dimensional attitude of the flow structures and permits their measurement with a degree of accuracy comparable to that inherent in the original field measurements.

When both flow layers and flow lines are present, surfaces exhibiting traces of the flow planes are selected (all surfaces of Fig. 5 except numbers 6 and 9). The dip and strike of the flow layers can then be determined geometrically by reversing the construction procedure on the graph paper layout thus finding the plane responsible for the attitude of mineral lineations on the selected model surfaces.

The coordinates of flow lines within a flow layer are determined from lineations on model surfaces more or less parallel to the plane of flow, e.g. triangular surfaces 6 and 9 of Fig. 5. Under certain conditions a graphic solution (Lowe, 1945) may be employed by finding the line of intersection (representing the flow line) between the flow layer and a plane containing the lineation direction on the particular surface and being perpendicular to the latter. Application of this construction to all surfaces showing flow line trend usually results in several possible answers.

The median of the bearings and plunges⁵ is taken as the acceptable solution.

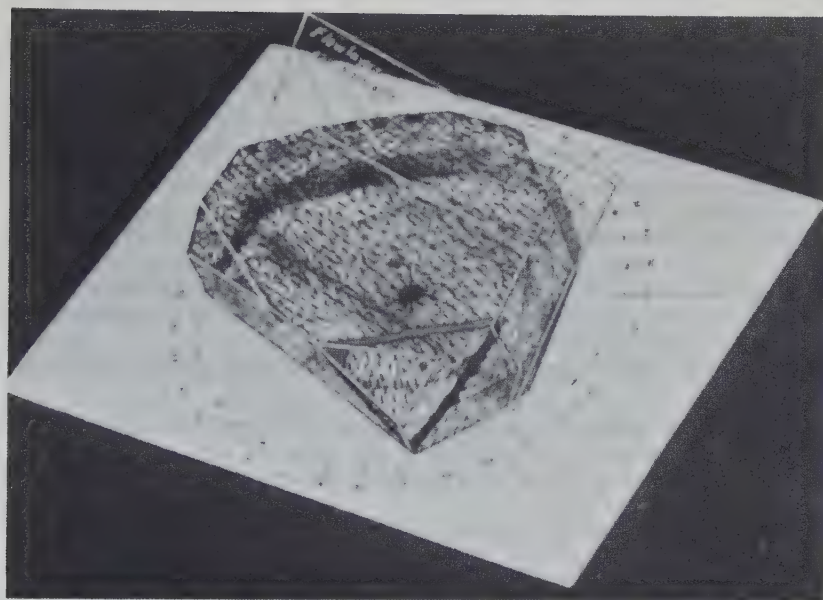


FIG. 7. Transparent acetate model of outcrop illustrated in Fig. 5 showing flow structures, joint systems and granite pegmatite dike.

Unusual cases where the linear elements do not lie in the plane of flow cannot be detected by study of the model.

Inspection of the model also facilitates the recognition and classification of joint systems in relation to the flow structures (Balk, 1937, part I.).

CONCLUSION

The construction of transparent models based on field data is a simple and helpful aid in the study of flow structures under adverse field conditions or when petrofabric analysis is not feasible due to lack of time or equipment. Once a certain facility of operation has been acquired, even relatively complex models can be constructed in 8 hours or less.⁶ Another advantage lies in the fact that the results obtained represent the average

⁵ Plunge may be defined as the angle which a line in space makes with the horizontal, measured in a vertical plane (Billings, 1942, p. 44).

⁶ Six hours were spent on the construction of the model shown in Fig. 7.

for an entire outcrop, a feature which is particularly desirable in regional and reconnaissance investigations. The degree of accuracy falls within the usual limits of error inherent in the original field measurements.

This method is also valuable as a training aid by giving students of structural petrology a means of visualizing the three-dimensional aspect of internal flow structures. The writer has found that the student's ability to recognize the more obscure and complex flow structures in the field was greatly improved after construction and study of a few models.

REFERENCES

- BALK, R. (1937), Structural behavior of the igneous rocks: *Geol. Soc. Am.*, Memoir 5, part I.
- BILLINGS, M. P. (1942), Structural Geology. Prentice-Hall, N. Y., 44, 135, 422.
- BUCHER, W. H. (1944), The stereographic projection, a handy tool for the practical geologist: *Jour. Geol.*, 52, 191-212.
- FAIRBAIRN, H. W. (1942), Structural Petrology of Deformed Rocks. Addison-Wesley Press, Cambridge, Mass., 107.
- INGERSON, E. (1942), Apparatus for direct measurement of linear structure: *Am. Mineral.*, 27, 721-725.
- LOWE, K. E. (1945), A graphic solution for certain lineation problems: (Abstract) *Bull. Geol. Soc. Am.*, 56, 1179.
- WEEMS, P. V. H. (1938), Air Navigation. 2nd Ed., McGraw-Hill, N. Y., 52.

MINERALOGY OF CONCRETIONS FROM PITTSBURGH COAL SEAM, WITH SPECIAL REFERENCE TO ANALCITE¹

WILDER D. FOSTER² AND FLORENCE L. FEICHT³

ABSTRACT

Four concretions were found in the Pittsburgh coal bed at Pursglove, Monongalia County, West Virginia, and were collected for study to obtain a better understanding of acid formation in the mine. Three of the concretions were mainly pyrite and the fourth was mainly dolomite. Associated with one or more of these concretions were these minerals: analcite, brammallite, calcite, dolomite, kaolinite, melanterite, pyrite, and an unknown mineral. The Pittsburgh coal bed is of Pennsylvanian age, and the base of the Monongahela formation. Analcite has been found in sedimentary rocks, identified as a constituent of boiler scale, and synthesized under hydrothermal conditions. In all cases it has been formed under alkaline conditions; it is decomposed by acid. It is supposed that alkaline solutions containing sodium reacted with clay to form analcite. Acids in the coal bed could have been neutralized by ground water passing through a limestone bed a few feet above the coal.

Analcite was synthesized at atmospheric pressure and 90°C. by allowing NaOH solution to react on kaolinite for 29 days. Only a small amount was formed; most was unidentified material.

INTRODUCTION

In connection with studies relating to acid formation in coal mines, four concretions, supposedly of the sulfur-ball type, were obtained. Determination of the minerals in these concretions seemed desirable to provide a better basis for understanding their origin, even though such information may not apply directly to the acidity of mine water. Acid conditions are closely connected with decomposition of the pyritic minerals, which are commonly predominant in concretions of this general character.

SOURCE AND GENERAL DESCRIPTION OF SAMPLES

These samples were collected from the Pittsburgh coal bed at the Pursglove No. 15 mine of the Pursglove Coal Mining Company, Pursglove, Monongalia County, West Virginia. This region, known as the Scotch Run Area, is just west of the Monongahela River and about five miles south of the Pennsylvania state line.

¹ Presented at the annual meeting of The Mineralogical Society of America, Pittsburgh, Pa., December 27, 1945. Published by permission of the Director, Bureau of Mines, U. S. Department of the Interior, Washington, D. C.

² Chemist-Petrographer, Health Division, Bureau of Mines, Central Experiment Station, Pittsburgh, Pa.

³ Physicist, Health Division, Bureau of Mines, Central Experiment Station, Pittsburgh, Pa.

The specimens were about 15 to 20 cm. in the longest dimension and weighed approximately 1 to 2 kg.

MINERAL ASSOCIATION IN THE CONCRETIONS

All of the minerals were identified by x -ray diffraction; the identification of those minerals of particular interest was confirmed by petrographic methods. The minerals are tabulated in Table 1 and were identified either as a part of the concretion or associated with it.

TABLE 1. MINERALS FOUND IN THE SPECIMENS

Constituent	Concretion No. 1	Concretion No. 2	Concretion No. 3	Concretion No. 4
Major	Pyrite	Pyrite	Pyrite	Dolomite
Other Minerals	Kaolinite Unknown	Analcite Calcite Melanterite Unknown	Calcite Dolomite	Pyrite Calcite Brammallite

As shown in Table 1, three of the concretions were sulfur balls, and the fourth was mainly dolomite, resembling the coal-ball type in its woody cellular structure, although it was not typical of this type of concretion. No typical coal balls are known from the Appalachian coal field.

DESCRIPTIVE MINERALOGY

Analcite.—Analcite was found adjoining concretion No. 2, filling in a series of parallel cleat joints of the coal and adhering to the concretion. These joint fillings made a very intimate contact with the pyrite nodule but did not seem to extend into it. The analcite was white and was accompanied by a trace of calcite. Microscopically, it occurred in thin plates and was either isometric or weakly birefringent and uniaxial negative; in both cases the index of refraction was 1.485 ± 0.003 . The spacings and intensities of its x -ray diffraction lines are listed in Table 2.

Brammallite.—Brammallite,⁴ a high-sodium illite, has been described only recently. It occurred as a white inclusion in concretion No. 4. A semi-quantitative spectrographic analysis showed several per cent of sodium, calcium, aluminum, iron, and silicon. Microscopically it had undulatory extinction and was biaxial negative with parallel extinction, and positive elongation. The indices were: $\alpha = 1.55^+$, $\gamma = 1.57^+$. The

⁴ Bannister, F. A., Brammallite (sodium illite), a new mineral from Llandebie, South Wales: *Mineral. Mag.*, **26**, 304-307 (1943).

axial angle is uncertain but may be small. *X*-ray data are given in Table 3. This is the second sodium-bearing mineral found in these concretions.

Calcite.—Traces of calcite were found in concretions Nos. 2 and 4. It was abundant in a joint crack outside concretion No. 3, in places inside the ball, and in surface depressions as a reddish or brownish material associated with dolomite.

Dolomite.—A little reddish or brownish dolomite was associated with calcite in concretion No. 3 in surface depressions. Brown dolomite was the major constituent of concretion No. 4.

Kaolinite.—Large amounts of kaolinite were found in concretion No. 1 as light-colored inclusions in the surface and inside.

Melanterite.—A small amount of melanterite coated concretion No. 2; it was also found inside on some partings.

Pyrite.—Pyrite was the major constituent of concretions Nos. 1, 2, and 3; a trace was also present in No. 4. Marcasite was not found. Pyrite tends to form at a higher *pH* than marcasite. Two of the three sulfur balls oxidized rapidly and disintegrated while standing in the laboratory; the third was relatively inert. Bain⁵ reported that pyrite that weathers easily has a high electrical conductivity, while more stable pyrite has only a low conductivity; however, all three of these samples were of a uniformly low conductivity.

Unknown.—An unknown mineral was found. It was most abundant as a thin coating on concretion No. 2; smaller amounts were found on No. 1. Further studies to identify this mineral are in progress.

DISCUSSION OF FORMATION OF ANALCITE

Since analcite has been found only occasionally in sedimentary mineral deposits and has not previously been reported in coal deposits, the following discussion relates particularly to its occurrence and formation.

The Pittsburgh coal bed forms the base of the Monongahela series of the Upper Pennsylvanian. Deposition continued on into Permian time, when there was an uplift, and Monongalia County has been above sea level ever since. Approximately 1400 to 1500 ft. of strata now remain above the Pittsburgh coal⁶ in Monongalia County. Undoubtedly other strata were deposited and completely eroded, but the geological consensus is that the temperature of the coal never far exceeded 100°C., due to depth of burial.

According to Schopf,⁷ the concretions in coal are generally formed

⁵ Bain, G. W., Pyrite oxidation: *Econ. Geol.*, **30**, 166-169 (1935).

⁶ Hennen, R. V., and Reger, D. B., *West Virginia Geol. Sur. County Report*: Marion, Monongalia, and Taylor Counties pp. 90-94 (1913).

⁷ Schopf, James M., Paleobotanist, Coal Constitution Laboratory, Central Experiment Station, Bureau of Mines, Pittsburgh, Pa. Personal communication.

TABLE 2. X-RAY POWDER DIFFRACTION DATA FOR ANALCITE SAMPLE COMPARED WITH PUBLISHED DATA

(Ni-filtered Cu radiation. Camera radius=203 mm. Calibration against quartz, pyrite, and kaolinite.)

Analcite in Concretion No. 2		Analcite ² (Mo radiation)	
Interplanar spacing, Å	Estimated intensity ¹	Interplanar spacing, Å	Intensity ¹
5.8	vs	5.59	.8
4.95	m	4.85	.4
		3.82	.1 ³
3.67	m	3.65	.2 ³
3.43	vs	3.43	1.0
		3.27	.1 ³
		3.04	.1 ³
2.93	vs	2.93	.8
2.81	m	2.79	.4 ³
2.68	s	2.69	.6
2.50	s	2.50	.6
2.43	m	2.42	.3
2.23	m	2.22	.4
2.17	w		
2.12	w	2.11	.05 ³
		2.08	.05 ³
2.02	w		
1.94	vw		
1.90	s	1.90	.5
1.87	m	1.86	.4
1.83	vw		
1.74	s	1.74	.6
1.71	m	1.717	.1 ³
1.69	m	1.681	.1 ³
1.66	w		
1.63	vw		
1.62	w	1.615	.05 ³
1.60	m	1.597	.1 ³
1.50	w	1.503	.1 ³
1.480	m	1.477	.1 ³
1.465	w		
1.445	w	1.444	.05 ³
1.415	m	1.415	.4 ³
1.390	vw		
1.380	w		
1.360	m	1.358	.4 ³
1.310	w	1.309	.1 ³
1.285	m	1.285	.1 ³
1.265	w	1.260	.1 ³
1.245	vw		
		1.238	.05 ³
1.220	m		

¹ vs=very strong; s=strong; m=medium; w=weak; vw=very weak.² First Supplementary Card File of X-ray Diffraction Data, 1944. Compiled and published by joint committee of A.S.T.M., American Society for X-ray and Electron Diffraction, and Institute of Physics of London.³ Not given by all sources.

TABLE 3. X-RAY POWDER DIFFRACTION DATA FOR BRAMMALLITE SAMPLE COMPARED WITH PUBLISHED DATA ON BRAMMALLITE AND ILLITE

(Ni-filtered Cu radiation. Camera radius=203 mm. Calibration against dolomite, pyrite, and talc.)

Brammallite in Concretion No. 4		Brammallite ² (Fe radiation)		Illite ² (Mo radiation)	
Interplanar spacing, A	Estimated intensity ¹	Interplanar spacing, A	Intensity	Interplanar spacing, A	Intensity
10	s	10.2	1.0	10.0	1.0
		4.8	.5	4.9	.4
4.45	s	4.4	1.0	4.46	1.0
				4.11	.2
		3.6	.5	3.64	.2
				3.4	.2
				3.33	.7
3.19	vs	3.2	1.0	3.2	.2
				2.98	.4
		2.81	.5	2.83	.3
		2.69	.2		
2.54	m	2.54	.9	2.56	1.0
		2.43	.7	2.44	.4
		2.34	.7	2.37	.5
				2.24	.6
		2.15	.5	2.18	.4
				2.12	.4
		1.95	.5	1.99	.5
		1.68	.5	1.65	.3
		1.64	.7	1.64	.5
1.488	m	1.49	1.0	1.50	.9
				1.38	.4
				1.35	.2
1.285	w	1.28	.6	1.30	.5
		1.26	.2	1.25	.4
		1.24	.5		

¹ vs=very strong; s=strong; m=medium; w=weak.² First Supplementary Card File of X-ray Diffraction Data, 1944. Compiled and published by joint committee of A.S.T.M., *American Society for X-ray and Electron Diffraction*, and *Institute of Physics of London*.

early in the peat stage; the coal around them is later compressed, but the concretions are not altered materially by such diagenetic and low-pressure metamorphic adjustments. Possibly initial deposition of the pyrite may be associated with bacterial decomposition in the peat.

The joint cracks in the coal were formed after the coal was indurated, much later than the formation of the concretions.⁷ They were probably formed by tangential stresses on the bed during the Appalachian revolution.

Sedimentary analcite has been reported twice in this country; in both cases volcanic ash fell into a mineralized lake, probably alkaline, and the dissolved salts reacted to form analcite.^{8,9} Bradley⁹ also refers to two German occurrences of sedimentary analcite, one associated with a clay ironstone (argillaceous siderite) concretion in a clay formation.

Analcite was discovered by Powell¹⁰ as a constituent of boiler scale, where the boiler-water temperature was 290°C. He refers to two papers of interest; one reported the synthesis in 1880 of analcite from sodium aluminate and sodium silicate solutions in a sealed copper tube at 180°C.; the other stated that analcite will form from its components in a closed system between 180° and 430°C. Powell, Carpenter, and Coates¹¹ report the finding of the silicates analcite, noselite, and natrolite; they were identified both by x-ray diffraction and petrographic analysis. Imhoff and Burkardt^{12,13,14} published numerous x-ray diffraction patterns for minerals found in scale deposits, among them analcite.

Noll synthesized analcite under hydrothermal conditions.¹⁵ He used a sodium hydroxide solution, hydrated alumina and silica—mol. ratio $\text{NaOH}:\text{Al}_2\text{O}_3:\text{SiO}_2=1:1:4$, at a temperature of 300°C., with a corresponding saturated vapor pressure of 87 atmospheres, and a reaction time of 15 and 24 hours.

Straub¹⁶ also has synthesized analcite. He used sodium silicate solution, various amounts of water, and solid sodium aluminate in a bomb at

⁸ Ross, Clarence S., Sedimentary analcite: *Am. Mineral.* **26**, 627–629 (1941).

⁹ Bradley, W. H., The occurrence and origin of analcite and meerschaum beds in the Green River formation of Utah, Colorado, and Wyoming: *U. S. Geol. Sur. Prof. Paper No. 158A* (1930), pp. 1–7.

¹⁰ Powell, Sheppard T., A critical study of boiler scales and advanced methods of analyses and identification: *Combustion*, **5**, 15–19 (Sept. 1933).

¹¹ Powell, Sheppard T., Carpenter, Lewis V., and Coates, John J., Complex silicate scales in high pressure boilers: *Combustion*, **11**, 18–24 (Aug. 1939).

¹² Imhoff, C. E., and Burkardt, L. A., X-ray fingerprints scale deposits: *Power*, **86**, 10–12 (Jan. 1942).

¹³ Imhoff, C. E., and Burkardt, L. A., X-ray diffraction methods in the study of power plant deposits: *Proc. Am. Soc. Testing Mater.*, **43**, 1276–1288 (1943).

¹⁴ Imhoff, C. E., and Burkardt, L. A., Crystalline compounds observed in water treatment: *Ind. Eng. Chem.*, **35**, 873–882 (1943).

¹⁵ Noll, W., The conditions for formation of kaolinite, montmorillonite, sericite, pyrophyllite, and analcite: *Mineral. Petrol. Mitt.*, **48**, 210–247 (1936).

¹⁶ Straub, Frederick G., Analcite, preparation and solubility between 182° and 282°C.: *Ind. Eng. Chem.*, **28**, 113–114 (Jan. 1936).

282°C. for 46 hours. The vapor pressure for pure water at 282°C. is 960 lbs. per sq. in. The calculated hydrostatic pressure at the coal bed is 650 lbs. per sq. in. for the 1500 ft. of rock now remaining. The pressure is of the right order of magnitude for the formation of analcite.

It is evident that analcite needs alkaline conditions for its formation. It is destroyed by acid, and yet acid conditions are more probable in a consolidating coal bed.

The analcite with the sulfur balls may have formed directly from its components, or again sodium in alkaline solution, possibly in connate waters, reacted with clay-like minerals to form the analcite. The analcite was reported to be in thin plates and may be a pseudomorph of a clay mineral. Since the analcite was found in a joint crack, it apparently did not form until after the joint cracks had formed, which would allow a freer circulation of the ground waters.

In order to account for the alkaline conditions which are necessary for the formation of analcite, it is necessary to consider the geological column above the Pittsburgh coal.¹⁷ Immediately above the coal are usually several feet of shale. Directly above is the Upper Pittsburgh sandstone; this is developed east of the Monongahela River and is about 25 ft. thick. However, west of the Monongahela, where the analcite occurs, it is largely replaced by limestone. Above is the Redstone limestone 5 to 15 ft. thick. Calcium bicarbonate solutions originating at various times in these limestones could have percolated down to the coal bed and neutralized the acids, allowing the analcite to form. The presence of pyrite instead of marcasite also suggests alkaline conditions.

The juxtaposition of the analcite and the concretion may be entirely fortuitous. Or this concretion may have mechanically blocked water circulation in the joints, and the stagnant region may have favored mineral deposition.

SYNTHESIS OF ANALCITE AT ATMOSPHERIC PRESSURE

An attempt was made to synthesize analcite from clay and an alkaline solution containing sodium in order to study the formation of analcite. A solution of 10 gm. of sodium hydroxide of A.R. grade in 100 ml. distilled water was put in a bottle with 7 gm. of kaolinite from Langley, S. C., placed in a drying oven at 90°C., and agitated occasionally. Samples were taken at 11 and 29 days.

The 11-day sample when examined microscopically appeared much like the kaolinite, but the mean index was 1.50. An x-ray diffraction pattern indicated sodalite, a sodium aluminum silicate containing chlorine.

¹⁷ Hennen, R. V., and Reger, D. B., Work cited in footnote 6, pp. 262-265.

Since no chlorine was present in the original solution this might be a hydroxyl-sodalite, as some replacement of chlorine by water has been reported.¹⁸ A chemical analysis showed a trace of chlorine and a loss on ignition of 14.6 per cent. The 29-day sample contained mostly spherulites of a mean index of 1.49. X-ray diffraction showed a small amount of analcite and a large amount of an unidentified material.

In a second test sodium chloride was substituted for sodium hydroxide. Both petrographic and x-ray diffraction methods showed unchanged kaolinite at 11 days and 29 days.

In a third test sodium chloride and sulfuric acid were substituted for the sodium hydroxide. Microscopically the 11-day sample looked like unchanged kaolinite, except the refractive index was 1.455 ± 0.005 . About 5 per cent had a higher index. Small amounts of kaolinite and anatase were identified by x-ray diffraction. The 29-day sample was similar microscopically, except the mean index was 1.460 ± 0.005 . The x-ray diffraction showed no kaolinite, a small amount of anatase, and a trace of sodium chloride. Also doubtfully identified were $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ and diaspora. The anatase probably was an inclusion in the kaolinite.

SUMMARY

Three sulfur balls and one other concretion collected from the Pittsburgh coal seam in West Virginia were examined by petrographic and x-ray diffraction methods. The following minerals were identified: analcite, brammallite, calcite, dolomite, kaolinite, melanterite, and pyrite. A discussion on the occurrence and formation of analcite is included. The presence of analcite indicates that waters penetrating the joint cracks of the juvenile coal bed were alkaline in their reaction.

¹⁸ Dana, E. S., *The System of Mineralogy*, 6th Ed. (1914), John Wiley & Sons, Inc., p. 1134.

ARTINITE FROM LUNING, NEVADA

CORNELIUS S. HURLBUT, JR., *Harvard University, Cambridge, Mass.*

ABSTRACT

At Luning, Nevada, veins cutting massive brucite are made up of hydromagnesite, granular brucite and acicular artinite. This is the second reported locality for artinite in the United States. Unit cell dimensions are: $a_0=16.54 \text{ \AA}$, $b_0=3.14 \text{ \AA}$, $c_0=6.18 \text{ \AA}$; $\mu=81^\circ 4'$ determined by the optical goniometer. New optical properties: $Z \wedge c=30^\circ$, $2V=60^\circ$. Composition: MgO 41.81%, CO₂ 22.8%, H₂O 35.46%. Differential thermal analysis curves of artinite and hydromagnesite are given.

INTRODUCTION

In the fall of 1942 Mr. Alan B. Shaw brought to the Department of Mineralogy at Harvard University a suite of specimens collected from the then recent workings of Basic Magnesium Inc. at Luning, Nevada. Most of these were brucite similar to that mined and shipped for calcining to MgO. In addition to the massive brucite there were several specimens of vein material. Mineralogically the veins proved to be made up of hydromagnesite, brucite and artinite.

The sections of the veins available for examination are from three to five centimeters across and in general are zoned parallel to the wall as shown in Fig. 1. The hydromagnesite in contact with massive brucite

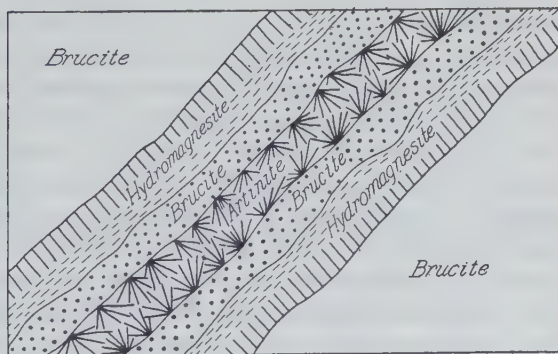


FIG. 1. Artinite vein.

is coarsely fibrous with the fibers standing at right angles to the vein walls. Between three and six millimeters from the walls the fibrous hydromagnesite grades into a fine granular hydromagnesite. In some specimens this textural break is the locus of small discontinuous open spaces. A sharp but irregular contact exists between the granular hydromagnesite and the narrow zone of fine granular brucite. There is no

textural break at this contact and the distinction between the two minerals in the hand specimen is made only by the slight color difference. Hydromagnesite is chalky white, while the brucite is grayish with a slightly greasy luster.

At places in the center of the veins the two narrow bands of brucite meet, but elsewhere open spaces exist in which artinite is present. The artinite forms delicate radiating aggregates of acicular crystals having a maximum length of one centimeter. The crystals are rhombic in cross section with a maximum width of about 0.08 millimeter. One specimen about one centimeter thick and ten centimeters in diameter appears to have been broken from the center of a vein and is made up entirely of a compact aggregate of artinite fibers crossing one another at various angles.

A thin section across the vein shows artinite fibers growing into the open center of the vein and at the same time replacing the adjacent granular brucite. A few grains of magnesite are present between the fibers.

CRYSTAL MEASUREMENTS

An effort was made on many artinite crystals to obtain angular measurements using the two-circle goniometer. The crystals were mounted so that the long dimension [010], was the axis of rotation. Artinite is monoclinic elongated on the *b* crystal axis and for this reason for many years was believed to be orthorhombic. No readings could be made on the terminal faces and the only satisfactory readings obtained were on the forms {100} and {001}. The angle between these two forms as measured on ten crystals varied from $80^{\circ} 56'$ to $81^{\circ} 11'$, with an average of $81^{\circ} 3'$. Highly perfect cleavage is parallel to {100} and a cleavage only slightly less perfect is parallel to {001}. The angle between the cleavages as measured on the optical goniometer is $81^{\circ} 4'$. This cleavage angle, in very close agreement with the average of the interfacial measurements, is believed to be the best measurement and is used in subsequent calculations. However, it compares poorly with an angle of $80^{\circ} 15'$ reported by Heritsch (1940) from *x*-ray measurements.

UNIT CELL AND SPACE GROUP

Rotation and zero and first layer line Weissenberg *x*-ray photographs were taken rotating about the axis of elongation. The dimensions of the unit cell thus obtained check closely similar data given by Heritsch (1940) on artinite from Kraubath, Styria. His data are listed for comparison.

DIMENSIONS OF UNIT CELL

Nevada	Styria
$a_0 = 16.54 \text{ \AA}$	$a_0 = 16.66 \text{ \AA}$
$b_0 = 3.14 \text{ \AA}$	$b_0 = 3.14 \text{ \AA}$
$c_0 = 6.18 \text{ \AA}$	$c_0 = 6.20 \text{ \AA}$
$\mu = 81^\circ 4'$	$\mu = 80^\circ 15'$

The Weissenberg photographs show a base centered lattice with $C2$, Cm and $C2/m$ possible space groups.

COMPOSITION

A chemical analysis of artinite from Nevada made by Mr. Forest Gonyer yields the following:

MgO 41.81%, CO_2 22.82%, H_2O 35.46%.

This corresponds closely to analyses of artinite from other localities and to the theoretical composition given by the formula $\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$. The unit cell contains two molecules.

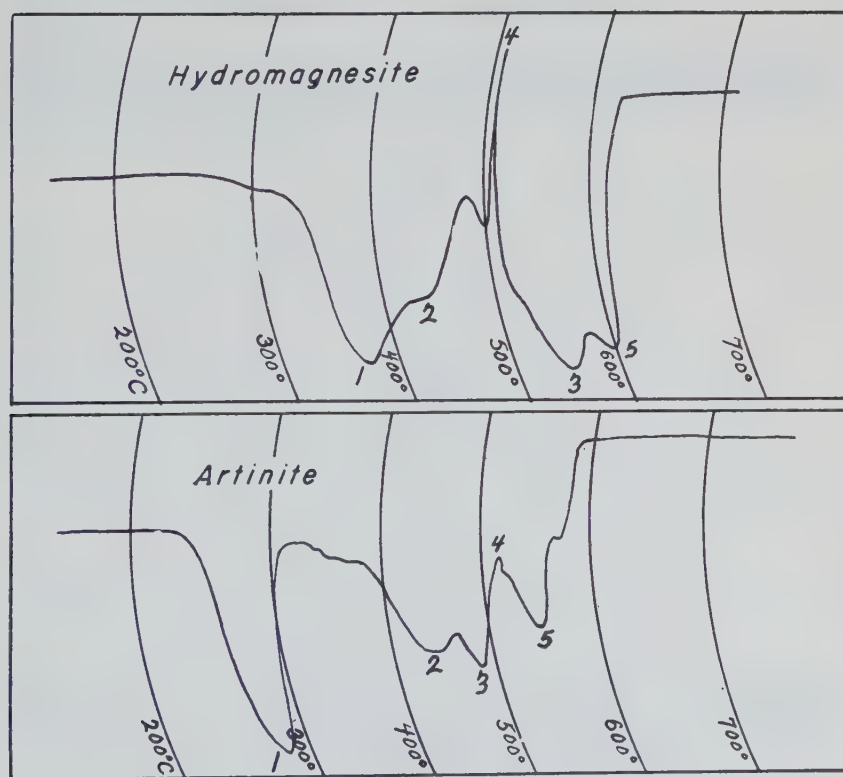


FIG. 2. Differential thermal analysis curves of hydromagnesite and artinite.

In Fig. 2 is reproduced a differential thermal analysis curve of artinite with one of hydromagnesite, $3\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 2\text{H}_2\text{O}$, for comparison. These were made by Mr. Carl W. Beck on recording equipment he designed in connection with a thesis problem at Harvard University. The numbered peaks on the two curves correspond to one another. The loss of H_2O (1) is at a lower temperature in artinite than in hydromagnesite; (2) is the loss of (OH) ; and (3) and (5) are the losses of CO_2 . All of these peaks indicate endothermic reactions. Peak (4) on both curves indicates an exothermic reaction and is interpreted as the inversion of amorphous MgO to periclase.

OPTICAL PROPERTIES

The optical properties of artinite can be summarized as follows:

$n_{\text{Na}} \pm 0.001$	
$X = 1.488$	Opt. (-)
$Y = 1.534 = b$	
$Z = 1.556 \wedge c = 30^\circ$	$2V = 60^\circ$.

The plane of the optic axes is at right angles to the b axis, the zone of elongation. The optical orientation is such that an optic axis emerges

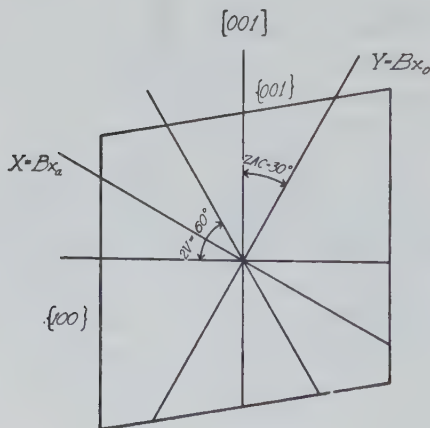


FIG. 3. Optical orientation of artinite.

perpendicular to the better cleavage $\{100\}$ as shown in Fig. 3, and thus the optical character is easily obtained,

OCCURRENCE OF ARTINITE

This occurrence at Luning, Nevada, is the second reported locality for artinite in the United States.* The other locality is at Hoboken, New Jersey, where radiating crystals are in veins in serpentine. Specimens from Hoboken labeled hydromagnesite were reported by Ferrari and Ghiron (1931) to be artinite. An examination of specimens in the Harvard Museum from Hoboken labeled hydromagnesite has shown that only about half of them are correctly labeled and that the others are actually artinite. It is probable that other collections also have artinite from Hoboken incorrectly labeled.

Outside of the United States artinite has been reported only from Styria and from Italy, where it occurs at several localities associated with serpentine.

REFERENCES

- FERRARI, A., AND GHIRON, D. (1931), Sopra una artinite di Hoboken, N. J.: *Periodico Min. Roma.*, **2**, 286-288.
HERITSCH, H. (1940), Gitterkonstanten und Raumgruppe des Artinites: *Zentr. Min.*, Abt. **A**, 25-31.

* Since this manuscript was submitted for publication, artinite has been reported by Clifford Frondel at a mine of the Vermont Asbestos Co. near Eden Mills, Vt. Here it is found in serpentine associated with pyroaurite.

DRUSY VUGS IN A MONZONITE DIKE, BEARPAW MOUNTAINS, MONTANA¹

WILLIAM T. PECORA AND BERNARD FISHER

CONTENTS

Abstract.....	370
Introduction.....	370
Locality of the quarry.....	372
Geological setting.....	372
Summary.....	372
The monzonite dike.....	372
The drusy vugs.....	375
General statement.....	375
Form and size.....	375
Pegmatitic shell.....	375
Residual cavity.....	376
Mineral sequence.....	377
Descriptive mineralogy.....	377
General statement.....	377
Minerals of the monzonite.....	377
Minerals of the drusy vugs.....	378
Origin.....	381
General.....	381
Formation of the original cavities.....	381
Considerations of temperature and pressure.....	382
Deposition of the vug minerals.....	382
Proposed hypothesis.....	383
Relation to miarolitic cavities.....	384
Conclusions.....	385
References.....	385

ABSTRACT

A monzonite dike in the Beaver Creek Stock, Bearpaw Mountains, Montana, contains some isolated cavities characterized by the following minerals: microperthite, albite, hornblende, zircon, biotite, magnetite, sphene, epidote, actinolite, axinite, chlorite, prehnite, datolite, calcite, analcite, thomsonite, and pyrite.

This unique occurrence contributes significant evidence concerning the crystallization history of the monzonite through its magmatic, pegmatitic, and hydrothermal stages.

INTRODUCTION

More than 100 specimens of monzonite containing drusy vugs were collected from a small rock quarry in the Bearpaw Mountains near Havre, Montana (Fig. 1). Several tons of broken rock on the quarry floor gave a fine opportunity to assemble a representative suite of specimens from the thousands available. The original collection was made

¹ Contribution No. 277, Dept. of Mineralogy, Harvard University. Paper read at annual meeting Mineralogical Society of America, Dec. 1941.

by Pecora in 1937 and was augmented by subsequent collections in 1938-40 made by both authors and a number of their friends, including George Bowery, G. H. Brodie, E. L. Cherbonnier, Jacob Freedman, R. L. Griggs, E. H. Harp, J. B. Lyons, T. C. Marvin, J. I. Snow, and R. H. Worman.

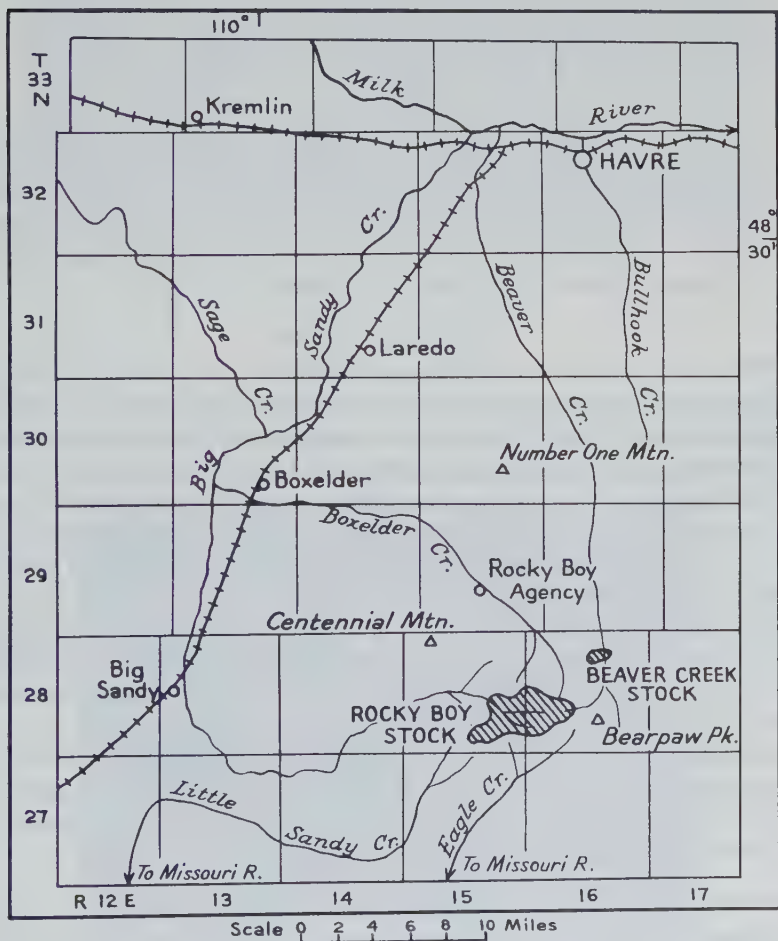


FIG. 1. Index map of a part of north-central Montana showing the location of the Beaver Creek stock.

Three fine crystals of hornblende in the original collection were studied crystallographically by Fisher, who also contributed to the study of several other minerals.

Field work was made possible by a grant from the Holden Fund, and laboratory studies were carried on at Harvard University. The authors are especially grateful to Professor E. S. Larsen. Messrs. E. B. Dane and B. M. Shaub kindly supervised the making of 2 photographs illustrating this report. The manuscript was critically read by Dr. Michael Fleischer.

The minerals that crystallized in these unusual vugs are so small that the binocular microscope and the immersion method have proved invaluable in studying age relations and making identifications.

LOCALITY OF THE QUARRY

The quarry from which the collections were made is situated in the Rocky Boy's Indian Reservation, along the Beaver Creek Road, on the west bank of Beaver Creek, about 22 miles south of Havre, Montana. In 1937 and 1938 this quarry was a source of rock used for small bridges being built along Beaver Creek by a unit of the Civilian Conservation Corps stationed about 15 miles south of Havre.

GEOLOGICAL SETTING

Summary

Monzonite is a common rock in the Bearpaw Mountains. Different varieties of monzonite make up some stocks entirely, as for example that of Number One Mountain (see index map). In the Rocky Boy Stock, masses of monzonite are intrusive into pyroxenite and shonkinite and are intruded by nepheline syenite and pegmatites, as described by Pecora (1942). In the Beaver Creek Stock, monzonite is exposed only as dikes in shonkinite.

Tiny shreds and knots of feldspar are common in the dark-colored monzonite of these stocks but it is only in one dike in the Beaver Creek Stock that well-defined vugs have been found. In many other monzonite dikes there are suggestions of the presence of similar vugs:

The igneous rocks of the Beaver Creek Stock were first described by Weed and Pirsson (1896). The stock is approximately one mile in diameter and is in contact with deformed beds of the Colorado Formation of Upper Cretaceous Age.

The monzonite dike

The monzonite dike in the Beaver Creek Quarry is illustrated in Fig. 2. The uppermost part of the dike is probably its original pinnacle, from which enclosing softer shonkinite has been eroded. The rock of the pinnacle, like that along the sides of the dike, is a dark, chilled monzonite. The lateral contact surfaces show a hexagonal joint pattern. The dike is about 2 feet thick at its pinnacle and about 50 feet below the top it is about 20 feet thick.

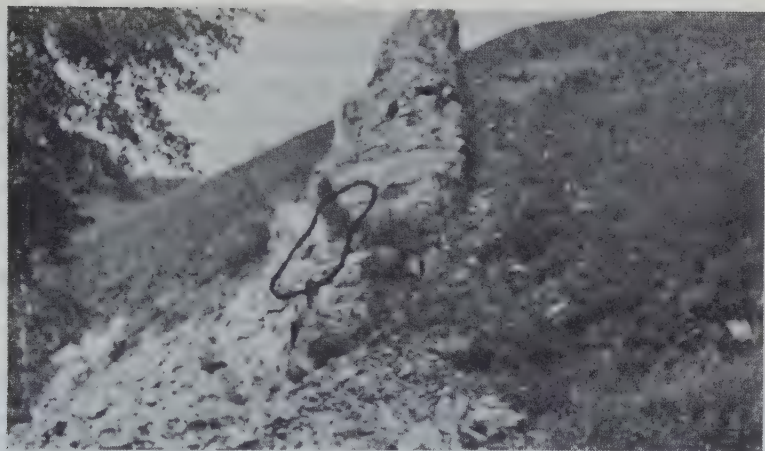


FIG. 2. The monzonite dike, Beaver Creek Quarry; the area containing the drusy vugs is outlined.

The vugs occur in the interior part of the dike some 30 feet below the pinnacle. The rock containing the cavities is fine-grained, grading into a finer-grained texture upward in the dike and a medium-grained texture



FIG. 3. Photomicrograph of a thin section of monzonite (crossed-nicols).

downward. In the upper part of the dike feldspathic shreds are common, and in the lower part neither cavities nor feldspathic shreds are present. The dike contains neither inclusions nor veins.

The principal minerals of the monzonite are augite, hornblende, biotite, plagioclase, and sanidine. Gradations in grain size in different parts of the dike are best characterized by the size of plagioclase laths imbedded in coarse sanidine. The texture of the rock in thin section is illustrated in Fig. 3. A modal analysis of two thin sections of the fine-grained rock is given below.

	Volume %
Augite.....	23
Hornblende.....	12
Biotite.....	7
Sanidine.....	38
Andesine.....	19
Accessory.....	1
	100

Several rock fragments were collected from the blocks that had been blasted from the dike, and a representative sample was analyzed (Table 1).

TABLE 1. CHEMICAL ANALYSIS (BY F. A. GONYER) AND NORM OF MONZONITE FROM THE DIKE IN THE BEAVER CREEK QUARRY, BEARPAW MOUNTAINS, MONTANA

<i>Analysis</i>		<i>Norm</i>	
SiO ₂	50.92	ne	7.1
Al ₂ O ₃	16.40	or	27.8
Fe ₂ O ₃	3.10	ab	18.3
FeO	6.06	an	14.2
MgO	4.16	di	15.9
CaO	7.64	ol	7.9
Na ₂ O	3.69	ap	1.7
K ₂ O	4.74	il	0.9
TiO ₂	0.47	mt	4.4
P ₂ O ₅	0.72		
MnO	0.07	C.I.P.W. position II. 6.2	
BaO	0.29	BOROLANOSE	
H ₂ O+	0.94		
Total	99.20		

S.G. (of hand specimen) = 2.73.

The groundmass of the monzonite containing the vugs, as shown by thin sections, is much more altered than that of monzonite elsewhere in the dike, principally illustrated by the hornblendization of the pyroxene and the change, locally, of feldspar to zeolites. Microperthite is much more abundant in the monzonite near the vugs than elsewhere.

THE DRUSY VUGS

General statement

The vugs occur only in one part of the dike, and contain or are filled by an array of minerals representing a long sequence of crystallization. The vugs have an outer light-colored shell and an internal cavity that is lined with minerals attached to the inner wall of the shell.

Form and size

The drusy vugs have a spheroidal or ellipsoidal form and are distinct with respect to host monzonite (see Fig. 4). The maximum diameter

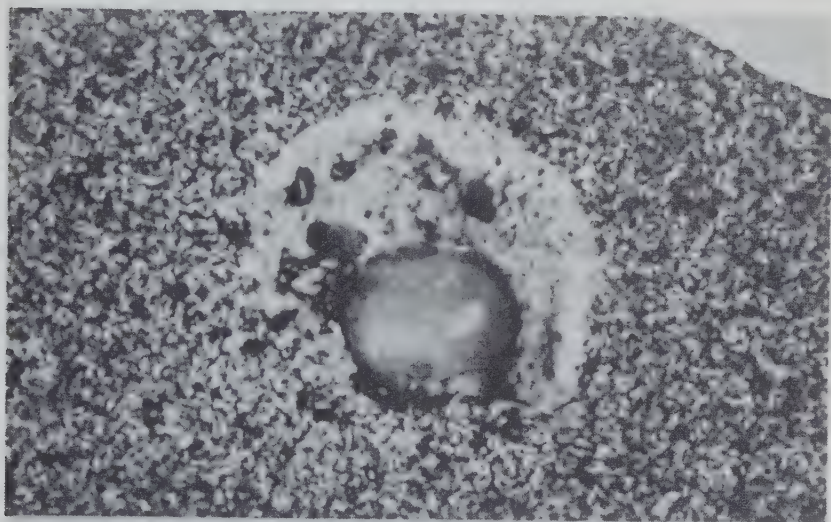


FIG. 4. Monzonite with a typical drusy vug containing albite tablets, a single rounded mass of prehnite, and smaller masses of calcite.

measured is 3 inches, but most are less than one inch. The vugs are individual units and none coalesces with another.

Pegmatitic shell

The shell is the outer rim of the vug and separates the cavity from the monzonite. In every specimen the shell is feldspar-rich, and for this reason it is sharply separated from the dark-colored monzonite. The shell is a syenite facies of the monzonite, and because of its much coarser grain size, it can perhaps also be considered the pegmatitic facies of the monzonite.

The shell is composed essentially of microperthite and albite tablets. Hornblende prisms are present in most of the specimens and magnetite octahedra in a few. Sphene, biotite, and zircon are rarely present. The microperthite has grown continuously from monzonite into the shell, but in larger size. The albite forms tablets projecting edgewise into the cavity. The hornblende and microperthite are of the same composition in both the monzonite and the pegmatitic shell. Andesine and augite, so common in the monzonite, are absent in the shell, and magnetite and albite are present only in the shell.

Rarely does the pegmatitic shell have a uniform thickness and there is a wide range in the proportions of feldspar and hornblende. In some specimens one side of the shell contains most of the hornblende prisms, conspicuous because the feldspathic shell is also thinnest or almost absent there. Commonly the bases of the hornblende prisms are intergrown with the feldspar tablets, and the terminal parts extend well into the cavity, either in free space or projecting through later-formed minerals.

The proportion of the shell to the size of the vug varies indirectly with the size of the vug; that is, the largest proportion of open space occurs in the largest vugs.

Residual cavity

The minerals that have formed in the cavities of the vugs are perched on or attached to crystalline faces or edges of albite, hornblende, and magnetite, and they themselves commonly form the loci for deposition of later-formed minerals. No one vug contains all of the minerals. The complexity of the mineral association has no apparent relation to the size of the vug. In many specimens one side of the inner wall of the shell is much richer in the late-formed minerals than the other.

The minerals attached to the cavity walls include:

1. Actinolite fibers.
2. Ball-like rosettes of green chlorite.
3. Sheaf-like forms of greenish-yellow epidote.
4. Aggregate plates of axinite.
5. Etched or rounded masses of calcite, datolite, prehnite, and analcime.
6. Tufts of radiating thomsonite.
7. Pyritohedra of pyrite.
8. Two unidentified silicate minerals.

Only a single mass of datolite or prehnite is found in any one vug, but several masses of the other minerals have formed in different parts of the same vug.

Hornblende and epidote are rare or absent in those vugs containing magnetite, and epidote is most abundantly formed in those vugs where

hornblende is scarce and magnetite is absent. Tufts of thomsonite are present in almost all of the cavities.

MINERAL SEQUENCE

The exact order of formation of the crystals in the vugs cannot be determined with any assurance for two principal reasons: (1) no one vug contains the entire array of minerals; and (2) selective deposition of some minerals offers a clue as to age relative to only one or a few other minerals in the same vug.

The sequence listed below is the best arrangement of the order of appearance (from top to bottom):

1. Albite (tablets), magnetite (octahedra), hornblende (prisms).
2. Actinolite (asbestiform).
3. Epidote (sheaves).
4. Axinite (aggregates of platy crystals).
5. Chlorite (rosettes of radiating scales).
6. Pyrite (pyritohedra).
7. Calcite (etched, rounded masses), datolite (white, glassy crystals), prehnite (rounded aggregates of plates).
8. Analcite (rounded crystals), thomsonite (moss-like tufts of needles).

In one specimen, hornblende engulfs a magnetite crystal; in another, datolite engulfs the corner of a calcite crystal. The position of pyrite in the sequence is not known with certainty, but it is older than calcite. The two unidentified minerals are both later than epidote, and perhaps also later than the calcite-datolite-prehnite group.

DESCRIPTIVE MINERALOGY

General Statement

In the general description of the minerals only the data pertinent to identification and occurrence are given. Refractive indices are correct to ± 0.003 but in some determinations the range is less.

Minerals of the monzonite

The *augite* in the monzonite is a zoned aegirine-augite, whose outer zones are pale green. The Z_n varies from 1.717 for the core to 1.725 for the outer zone.

The *hornblende* replaces augite in part. The following optical data are pertinent: Z = dark green; pleochroic; $Z_n = 1.706$; Biaxial (-).

On cleavage plates, the mean n of the *biotite* is 1.657.

The discontinuously zoned *plagioclase* has a composition ranging from andesine (An_{50}) for the cores to oligoclase (An_{20}) for the outer zones.

The *sanidine*, locally microperthitic, is the coarsest mineral in the rock and encloses most of the others poikilitically. The clear mineral is biaxial (-); $Y_n = 1.525$.

A much higher proportion of *microperthite* is present in the monzonite adjacent to the vugs, and it is rarely free of alteration.

Minerals of the drusy vugs

The last-formed plagioclase tablets in the shell are glassy in character and pure *albite* in composition; whereas earlier-formed chalky-white tablets are near oligoclase in composition.

Magnetite octahedra are imbedded in the earlier albite tablets. In one specimen the magnetite is clearly older than a hornblende prism that envelops it.

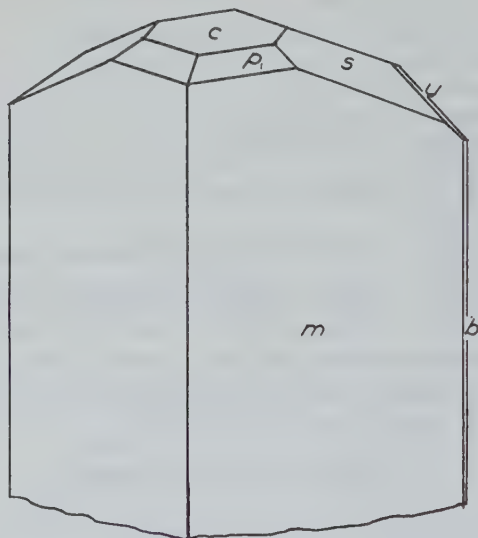


FIG. 5. Idealized drawing of hornblende crystal from the vugs in the monzonite dike.

A few crystals of zircon were recovered from a recess in the shell, but the relative age of its formation is obscure.

A special study of the *hornblende* prisms attached to the shell and projecting into the cavity was made by the writers. The crystals are are black, splendid, and, for the most part, well-terminated.

The optical data of the hornblende are:

Orientation	<i>n</i>	Pleochroism	
X	1.690	greenish-yellow	
Y	1.702	green	Bx neg. (-)
Z/ \wedge c = 16°	1.705	blue-green	2V very small

A composite drawing of the well-formed crystals, studied on a 2-circle goniometer, is shown in Fig. 5. Its crystallographic elements are listed

TABLE 2. CRYSTALLOGRAPHIC ELEMENTS OF HORNBLLENDE FROM THE VUGS IN MONZONITE, BEAVER CREEK QUARRY, BEARPAW MTS., MONT.

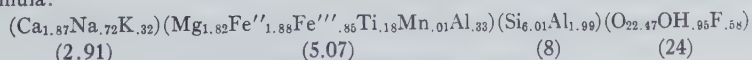
$$\begin{aligned}
 a:b:c &= 0.5451:1:0.2927 \\
 p_0:q_0:r_0 &= 0.5370:0.2825:1 \\
 r_2:p_2:q_2 &= 3.5400:1.9010:1 \\
 p_0' &= 0.5563 \quad q_0' = 0.2927 \quad \alpha_0' = 0.2706 \\
 \beta &= 105^\circ 08' \quad \mu = 74^\circ 52'
 \end{aligned}$$

Forms	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A
<i>c</i> 001	90°00'	15°18'	74°42'	90°00'	0°00'	74°42'
<i>b</i> 010	0°00'	90°00'	90°00'	0°00'	90°00'	90°00'
<i>m</i> 110	61°43'	90°00'	0°00'	61°43'	76°42'	28°17'
<i>s</i> 021	24°40'	32°55'	74°53'	60°25'	29°35'	76°54'
<i>p</i> 111	70°34'	41°17'	50°22'	77°19'	27°26'	51°31'
<i>d</i> $\bar{1}$ 11	315°40'	22°09'	105°53'	74°22'	15°38'	105°16'
<i>u</i> $\bar{1}$ 31	341°47'	42°36'	106°02'	49°59'	40°01'	103°13'

TABLE 3. CHEMICAL ANALYSIS (BY F. A. GONYER) OF HORNBLLENDE FROM THE VUGS IN THE MONZONITE DIKE, BEAVER CREEK QUARRY, AND THE CALCULATED FORMULA

	Per cent Oxides	Mol. No.	O	M	Mf
SiO ₂	38.92	.648	1.296	.648	6.01
TiO ₂	1.51	.019	.038	.019	.18
Al ₂ O ₃	12.68	.125	.375	.250	2.32
Fe ₂ O ₃	7.42	.046	.138	.092	.85
FeO	14.64	.203	.203	.203	1.88
MnO	.09	.001	.001	.001	.01
MgO	7.86	.196	.196	.196	1.82
CaO	11.24	.201	.201	.201	1.87
Na ₂ O	2.38	.039	.039	.078	.72
K ₂ O	1.58	.017	.017	.034	.32
H ₂ O+	.93	.051	.051	.102	.95
F	1.20	F ₂ = .031	.062	—	.58
	100.45		2.617		
O = F	.51		— .031		
	99.94		2.586		
			<i>f</i> = 9.281		

Formula:



in Table 2. A chemical analysis of the hornblende is given in Table 3. The specific gravity obtained with the Berman Density Balance is 3.35 ± 0.02). The optical data are like those for the variety known as *hastingsite* and are remarkably similar to the hornblende that has formed in the host monzonite.

The *actinolite* is asbestiform in habit, either (1) as a thin coating on the prism faces of the hornblende, or (2) as extensions of the prism from solid material to many single fibers, or (3) as solitary needles attached or enclosed by other minerals. The color is grass green to light green. The variable optical data indicate that the mineral has a range in composition. Z is pale green; X is yellow; $Z \wedge c = 14^\circ$; and $Z_n = 1.662$.

Epidote occurs as sheaf-like aggregates of plates having a brownish-yellow color on the surfaces but brilliant yellow color on broken faces. The optical data are listed below:

	<i>n</i>	Pleochroism	Bx neg. (—)
X	1.730	Colorless	$2V = 65^\circ$
Y	1.740	to	Dispersion $r < v$, perceptible
Z	1.745	pale yellow	Parallel extinction

Axinite occurs as aggregates of crystal plates projecting edgewise into the cavities from their base on albite. The color is light brown on the surface and pinkish brown on broken surfaces.

$$X_n = 1.680; \quad Y_n = 1.687; \quad Z_n = 1.690$$

$$\text{Bx neg. (—). } 2V = 70^\circ. \quad \text{Dispersion } r < v, \text{ strong.}$$

In one vug, axinite is coated with chlorite, and in others it seems to be contemporaneous or younger than epidote and actinolite.

Chlorite occurs as aggregates of plates arranged in a great number of clumps, or rosettes, that are perched on other minerals. The rosettes are soft and dark green in color.

Optical data are: Bx pos. (+), $2V$ = very small (almost uniaxial). $Z \perp$ cleavage. $Y_n = 1.612$. Chlorite is the youngest of the dark-colored minerals to form, and is one of the most common minerals. It is generally deposited on albite.

Pyrite in one cavity occurs as a pyritohedron truncated by subordinate octahedral faces. Pyrite is younger than albite and older than calcite.

Calcite, *prehnite*, and *datolite* are all younger than epidote and chlorite, but the relative ages of the prehnite and the other two are not clearly established. Datolite is younger than calcite. The three minerals each have a characteristic habit. Calcite appears as rounded, etched crystal masses; prehnite ($2V = 65^\circ$. Bx pos. (+). $Y_n = 1.625$. $Z = c$.) as bladed, spherical aggregates light green in color; and datolite ($2V = 85^\circ$. Bx neg. (—). $Y_n = 1.651$. $r > v$) occurs as glassy crystals with a pearly luster.

Analcite was observed in a few cavities as rounded, glassy crystals.

Thomsonite occurs principally as tufts, or as delicate moss-like coatings, composed of brilliant, radiating prismatic crystals. The mineral is principally formed on albite. Optical data are: Bx pos. (+). $2V=35^\circ$. $Y_n=1.535$, Y =elongation. In one vug, long fibrous aggregates of the thomsonite have different optical properties: $2V=50^\circ$, $Y_n=1.530$.

Two unidentified minerals were seen in the cavities. One, spherulitic balls composed of minute fibers, has refractive indices: lowest=1.606; highest=1.615. Other optical data are uncertain. The other mineral, composed of an aggregate of long, parallel, white fibers is uniaxial (-); $\omega=1.557$; $\epsilon=1.548$.

ORIGIN

General

Any hypothesis of origin of the drusy vugs must first explain the formation of the original cavities and then the process of deposition of the minerals on the walls of these cavities. In reviewing the evidence bearing on origin, the following features seem to have special significance:

1. The drusy vugs occur only near the top of the dike.
2. The contact surface of the drusy vugs with monzonite is rounded and clearly defined.
3. The larger drusy vugs have a higher proportion of residual open space than smaller ones.
4. Mineral assemblage and relative proportions of minerals vary in drusy vugs of the same or different size.
5. Hornblende and micropertthite are the only minerals common to both the monzonite and the drusy vugs, and they are coarser-grained in the vugs.

6. All of the minerals in the drusy vugs that formed later than albite and magnetite contain one or more of the following: H_2O , F, B, S, CO_2 .

Therefore, the writers believe that the cavities were formed by resurgent boiling and that the minerals were deposited in them by moving hot solutions.

Formation of the original cavities

The original cavities, that later became the drusy vugs, were a result of globules of vapor formed after the magma was intruded and before the magma was completely consolidated. Hypotheses postulating the formation of the cavities by solution of solid monzonite or by solution of inclusions are untenable.

The appearance of such globules of vapor, composed principally of water vapor but perhaps also of a subordinate amount of F, B, S, and CO_2 , can best be explained by the process of "resurgent boiling." The

rapidly crystallizing magma froze around these globules, leaving gas-filled cavities in hot rock. Vapor was also trapped in the interstices of the monzonite groundmass.

Considerations of temperature and pressure

If, as is held by the writers, resurgent boiling occurred before complete crystallization of the magma, some considerations of the temperature and pressure that prevailed may have a bearing on the geologic significance of such gases.

An ascending magma of monzonite composition and in the process of precipitating pyroxene was implaced at a probable temperature of 600°C. to 800°C. Although the cooling process was a rapid one, the vapor phase could have appeared at a temperature above 400°C.

The height of the column of rock above the pinnacle of the dike was, from field evidence, at least 3,000 feet and may have been as much as 7,000 feet. Under such conditions, the weight of the column exerted a confining pressure of at least 200 Kg/cm² and probably not more than 1,000 Kg/cm². The hydrostatic pressure of the magma fluid at the time of its implacement was, therefore, probably in excess of 200 atmospheres.

It is reasonable to conclude that the resurgent gases appeared at supercritical conditions for water vapor, that is, above 374°C. and 218 Kg/cm². The physical nature of gaseous material at such elevated temperature and pressure and its behavior with falling temperature are still puzzling problems. Perhaps the term "fluid" can best connote our present ignorance.

Deposition of the vug minerals

Two possible processes should be considered to explain the deposition of the minerals in the vugs: (1) condensation of the gaseous fluid in the original rock-walled cavities with concurrent precipitation of dissolved material; or (2) continuous migration of fluid into the cavities as temperature was lowered.

The heterogeneity of the mineral assortment, both quantitatively and qualitatively, is evidence against a simple hypothesis of condensation and resultant precipitation. It is reasonable, however, to postulate tentatively that a gas, or fluid, probably existing under supercritical conditions, could have effectively reacted with the already crystallized monzonite, both along the cavity walls and in the rock itself.

The change of pyroxene to hornblende, in the rock, involving the addition of H₂O and F to the mineral structure was probably caused by such a late-magmatic fluid, as was the apparent alteration of the feldspars in the groundmass of the hard, unweathered monzonite. Such reactions involve an exchange or removal of materials.

The writers support the hypothesis that such an exchange or removal of materials was responsible for adding to the residual fluid of the crystallized magma certain constituents that had already been utilized in making the magmatic minerals. In this regard the bulk composition of the vug minerals may have some significance.

A rough estimate was made of the proportions of the different minerals in the vugs and the approximate bulk composition of the vug minerals was calculated therefrom. Because of the method used, only the principal oxides were considered. Microperthite was not included as a vug mineral because of its apparent seriate textural gradation from the groundmass of rock to the shell of the vugs. Of the remaining minerals, albite makes up about 75 per cent; hornblende and actinolite 15 per cent; epidote 5 per cent; and prehnite about 5 per cent.

The bulk composition of the vug minerals and its relation to the composition of the monzonite is shown in Table 4 below:

TABLE 4. APPROXIMATE BULK COMPOSITION OF THE VUG MINERALS

	<i>Vug Minerals</i>	<i>Relation to rock analysis</i>
SiO ₂	61%	+10
Al ₂ O ₃	19	+ 3
Fe ₂ O ₃	2	- 1
FeO	3	- 3
MgO	1	- 3
CaO	5	- 3
Na ₂ O	8	+ 4
K ₂ O	1	- 4

The main difference between the two compositions is the greater proportion in the vug minerals of SiO₂, Al₂O₃, and Na₂O.

Proposed hypothesis

The hypothesis proposed by the writers to explain the distribution and origin of the drusy vugs in the monzonite dike is as follows:

1. The magma was implaced as a vertical dike whose form at the top was a pinnacle.
2. A gas phase appeared as crystallization was proceeding.
3. Gas globules, collecting near the top of the dike, were trapped by the rapid consolidation of the rock.
4. The residual volatile constituents both in the rock-walled cavities and in the groundmass of the rock, perhaps existing as a fluid in or near the super-critical state, reacted with the pyroxene, plagioclase, and sanidine of the rock.

5. A part of the constituents of the residual fluid reacted with the rock minerals to form, for example, hornblende from pyroxene. This process furnished material, which when added to the solutes already in the fluid, formed the minerals of the drusy vugs.

6. The greater alteration of the monzonite near the vugs than elsewhere in the dike suggests that the reworked constituents were obtained principally from the rock adjacent to the original cavities.

7. The mobile fluid that entered the cavities as temperature was falling augmented the supply already there. The vug minerals were precipitated from this hydrothermal solution.

The relative proportion of all the minerals in the drusy vugs to the quantity of monzonite containing them is so insignificant that the magma cannot be called volatile-rich.

As the temperature of the consolidated monzonite fell, the vapors originally filling the globular cavities contracted and thus provided space for additional fluids to enter, accumulate, and eventually precipitate. The transition of the gaseous fluid to the hydrothermal solution was probably gradual rather than abrupt, and it is quite likely that no sharp phase boundary was passed.

The basic physico-chemical principles of hydrothermal process have been ably reviewed by Morey and Ingerson (1937), and the nature, transition, and structure of pure fluids near and in the critical region have been investigated recently by Clark (1938), Maass (1938) and Barnes (1938).

Relation to miarolitic cavities

The term miarolitic cavity has often been used in the literature with reference to residual, crystal-lined cavities in intrusive, igneous rocks. This kind of mineral occurrence in diabase has been described by Shannon (1926) and Cannon (1937). Granite, however, is a much more common host for such cavities. The terms "druse," "drusy granite," "druse minerals," "miarolite," and "miarolitic cavity" have all been employed by writers describing such occurrences: Fournet (1841); Becker (1868); Schwantke (1890); Koenigsberger (1901); Gillson (1927); and Gallagher (1937).

The term drusy vug, however, is preferred in reference to such mineral occurrences, and it would be applicable to a wide assortment of occurrences irrespective of origin or rock composition. Miarolitic cavities could be more properly restricted to the original rock-walled, gas-filled cavity formed during consolidation of intrusive rocks through appearance of a gas phase in the late magmatic stage.

CONCLUSIONS

The drusy vugs in a monzonite dike in the Beaver Creek Quarry, Bearpaw Mountains, Montana, represent miarolitic cavities whose walls have been lined with minerals deposited by later-formed hydrothermal solutions. The minerals that compose the shell of each vug (microperthite, hornblende, albite, magnetite) represent a transitional stage (pegmatitic?) between the magmatic and hydrothermal stages.

The constituents making up the minerals of the drusy vugs were in large part derived through reaction on already crystallized rock-minerals by late magmatic volatile fluids that existed at or near supercritical conditions for water. In the groundmass of the rock this reaction is evidenced by the partial alteration of pyroxene to hornblende. In the monzonite adjacent to the drusy vugs the reaction has also resulted in noticeable alteration of feldspars. Na, Si, and Al have been more susceptible to transfer from rock to vug than K, Ca, Mg, and Fe; and in combination with volatile and other residual constituents these elements were precipitated from mobile hydrothermal solutions that entered the cavities probably by movement along the grain boundaries of the monzonite and by diffusion through it.

REFERENCES

- BARNES, W. H. (1938), The diffraction of x -rays by substances in the region of the critical point: *Chem. Rev.*, **23**, 29-46.
- BECKER, E. (1869), Über das Mineralvorkommen im Granit von Stiegau: *Neues Jahr. f. Min.*, 236-237.
- CANNON, R. S. (1937), Geology of the Piseco Lake Quadrangle: *N. Y. State Mus., Bull.* No. **312**, 33-35.
- CLARK, A. L. (1938), The critical state of pure fluids: *Chem. Rev.*, **23**, 1-16.
- FOURNET, J. J. (1841), Géologie de la partie des Alpes comprise entre Le Valais et L'Oisans: *Mem., Soc. Agr. Ann.*, **IV**, 506-519.
- GALLAGHER, D. (1937), Origin of the magnetite deposits at Lyon Mountain, N. Y.: *N. Y. State Mus., Bull.* No. **311**, 17-21.
- GILLSON, J. (1927), The granite of Conway, N. H., and its druse minerals: *Am. Mineral.*, **12**, 307-319.
- KOENIGSBERGER, J. (1901), Die Minerallagerstätten im Biotitprotogin des Aarmassivs: *Neues Jahr f. Min.*, Beil.-Bd., **14**, 115-119.
- MAASS, O. (1938), Changes in the liquid state in the critical temperature region: *Chem. Rev.*, **23**, 17-28.
- MOREY, G. W., AND INGERSON, EARL (1937), The pneumatolytic and hydrothermal alteration and synthesis of silicates: *Econ. Geol.*, **32**, Supp. No. 5, 607-761.
- PECORA, W. T. (1942), Nepheline syenite pegmatites, Rocky Boy Stock, Bearpaw Mts., Mont.: *Am. Mineral.*, **27**, 397-424.
- SCHWANTKE, A. (1890), Drusenmineralien des Striegauer Granits, Veit & Co., Leipzig, 87 pp.
- SHANNON, E. V. (1926), Mineralogy and petrology of the intrusive Triassic diabase at Goose Creek, Loudoun Co., Virginia: *Proc. U. S. Nat. Mus.*, **66**, Art. 2, 86 pp.
- WEED, W. H., AND PIRSSON, L. V. (1896), Igneous rocks of the Bearpaw Mts., Montana: *Am. Jour. Sci.*, 4th ser., **1**, 283-301; 351-362; **2**, 136-148; 188-199,

VIOLA'S ZONE-LAW

P. TERPSTRA AND R. TER VELD,
Crystallographic Institute, Groningen, Netherlands.

ABSTRACT

Viola's zone-law, that has been quoted without comments in textbooks, is not a general law. It is only correct if the crystallographic axes and the unit face have been chosen according to the orthodox crystallographic rules with respect to the symmetry elements; then however it holds true in more cases than had been foreseen by Viola.

In his textbook of Mineralogy (1) Niggli states the following thesis: "The face obtained by simple addition of the indices of two equivalent faces—for instance, $h_3 = (h_1 + h_2)$; $k_3 = (k_1 + k_2)$; $l_3 = (l_1 + l_2)$ —makes equal angles with these faces. It truncates the edge symmetrically."* In his edition of Klockmann's textbook of Mineralogy, P. Ramdohr makes a slight addition to the thesis and states: "Since a symmetrical truncation occurs *only* where the faces are equivalent, this problem finds its application chiefly on forms with many faces, thus especially in the cubic system" (2).

The same or nearly the same statements are in older textbooks and as early as 1905 C. Viola tried to give a *general* proof of this thesis (3). His proof is however far from correct, mainly as a consequence of a mistake in the application of the transformation of indices, but even besides these errors there are other inaccuracies in his proof. To demonstrate this we will first reproduce Viola's reasoning.

Let two equivalent faces h and k be given. The symbols of these faces are $h = (h_1 h_2 h_3)$ and $k = (k_1 k_2 k_3)$. From these the following faces are derived: $m = (h_1 + k_1, h_2 + k_2, h_3 + k_3)$ and $n = (h_1 - k_1, h_2 - k_2, h_3 - k_3)$. The statement is, that these faces m and n (a) bisect the angles included by the faces h and k .

To prove this statement Viola considers two cases, namely:

- (1) the faces h and k are equivalent by reflection in a plane of symmetry;
- (2) the faces h and k are equivalent by rotation around an axis of symmetry.

1st Case. The faces h and k are symmetrical about a plane of symmetry.

We transform the coordinates in such a manner that the symmetry plane has the symbol (010) and that (001) signifies a plane that is normal to this "new" (010). If (b) then the "new" indices of the face h be $x_1 x_2 x_3$, those of the face k must be $x_1 \bar{x}_2 x_3$. Consequently the "new" indices of the derived faces m and n are respectively:

$$m \dots (x_1 + x_1, x_2 + \bar{x}_2, x_3 + x_3) \text{ or } (2x_1, 0, 2x_3)$$

$$n \dots (x_1 - x_1, x_2 - \bar{x}_2, x_3 - x_3) \text{ or } (0, 2x_2, 0) \text{ or } (010);$$

i.e., the face n coincides with the symmetry plane and the face m is normal to this plane and belongs to the zone $[h, k]$. Since (010) bisects the angle between h and k the face m bisects the complementary angle.

2nd Case. The faces h and k are symmetrical about an axis of symmetry.

We let the direction [001] coincide with the axis of symmetry and we take the "new" [100] and [010] perpendicular to that axis. Let the "new" indices of the face

* Quotations translated in English.

- (c) h be $x_1x_2x_3$, then those of the face k are $y_1y_2x_3$. Consequently the symbols of the derived faces m and n are: $m \cdots (x_1+y_1, x_2+y_2, 2x_3)$ and $n \cdots (x_1-y_1, x_2-y_2, 0)$.

Since the third index of n is zero, the face n belongs to the zone $[001]$. Taking our next step, we choose this face n as (100) . This means that now $x_2=y_2$ and therefore the "new" symbols of our four faces are:

$$\begin{array}{ll} h \cdots (x_1x_2x_3), & k \cdots (y_1x_2x_3), \\ m \cdots (x_1+y_1, 2x_2, 2x_3), & n \cdots (x_1-y_1, 0, 0). \end{array}$$

- We now perform a third transformation, taking (010) normal to (100) . Since this transformation lies in the zone $[001]$ the indices x_1 and y_1 must be equal in value and this in such a manner that $x_1=-y_1$, for if $x_1=y_1$ all indices of the face n would become zero and this is impossible. The "newest" symbols of our four faces are therefore:

$$h \cdots (x_1x_2x_3), k \cdots (\bar{x}_1x_2x_3), m \cdots (0, 2x_2, 2x_3) \text{ and } n \cdots (2x_1, 0, 0).$$

The face m lies in the zone $[100]$ and the face n is the face (001) itself; thus they are perpendicular and consequently m and n bisect the angles included by the faces h and k . It is seen that the faces h and k are harmonically separated by the derived faces m and n .

Such was the proof given by Viola; our comments follow.

COMMENTS ON THE PROOF OF VIOLA

The statement represented by (a) is not generally true, as can be seen in the following examples (Figs. 1 and 2). Figure 1 is a part of the

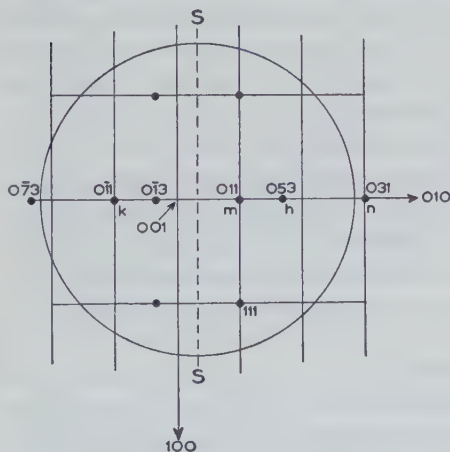


FIG. 1

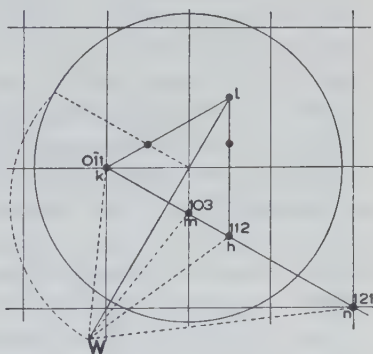


FIG. 2

gnomonic projection of a certain crystal; a plane normal to the vertical crystallographic axis has been selected as the plane of projection and the center of projection is situated upon the vertical line through the center of the circle at a distance equal to the radius of this "gnomon-circle." The pole (001) is to the left of the circle's center and the poles $(0kl)$ are seen aligned as usual on the line that points to the pole (010) . The poles $(0\bar{1}1)$, (001) , (011) , (021) , (031) , etc., divide this line in the usual man-

ner in equal parts and the distance of the pole (053) to (001) is $5/3$ times the length of those equal parts. With our special crystal this line happens to pass through the foot of the gnomon (= center of the circle) and moreover the distances of the poles (0 $\bar{1}1$) and (053) to the center of the circle are by chance alike. Hence the faces $h=(053)$ and $k=(0\bar{1}1)$ are symmetrical about the plane that is normal to the plane of projection along the line SS. These faces being therefore equivalent in the sense of Viola's thesis, the statement of which is that the faces $m=(044)$ or (011) and $n=(062)$ or (031) would bisect the angles included by the faces h and k . A glance at the projection suffices to show that this is not true.

It is easily seen that the peculiarity of this gnomogram is, that notwithstanding the fact that the crystal has a plane of symmetry, the plane (001) is not normal to the symmetry plane. That means that, in contravention of the orthodox rules, the crystallographic b -axis is not normal to the symmetry plane, but that some other edge of the crystal has been chosen for the b -axis.

Figure 2 is a part of the gnomonic projection of another crystal. The poles (0 $\bar{1}1$), (103), (112), (121) have been inserted by applying the usual rules to the primitive parallelograms, which here happen to be rectangles in which the long side is $\sqrt{3}$ times the other side. In consequence of this peculiarity the poles (0 $\bar{1}1$), (112), ($\bar{1}12$) are the corners of an equilateral triangle, that has its central point in the center of the circle. Hence the faces $h=(112)$ and $k=(0\bar{1}1)$ are symmetrical about a threefold axis of symmetry (in the circle's center normal to the plane of projection). Having constructed the angle point W to the zone $[h, k]$, one sees immediately that the faces $m=(103)$ and $n=(121)$ do not bisect the angles included by the faces h and k . In this case too the crystallographic axes have been chosen in an unorthodox manner, resulting in the peculiarity that, in spite of the axis of threefold symmetry, the three faces of the form have different figures in their symbols.

The conclusion of Viola indicated by (b) is not generally correct as is easily seen from Fig. 1. In this gnomogram h and k are symmetrical about the plane of symmetry SS; (010) coincides with the plane of symmetry and (100) is normal to it so that Viola's conditions are all satisfied. Yet the indices of h are 053 and those of k not 053 but 0 $\bar{1}1$.

The conclusion (c) does not hold as is seen in Fig. 2: [001] coincides with the axis of symmetry; [100] and [010] are perpendicular to [001]; the faces h and k are related about the symmetry axis and yet the indices of h are 112 and those of k are 0 $\bar{1}1$ instead of 1 $\bar{1}2$.

The statement (d) by Viola makes an implicit assumption about the transformation. In the following paragraph it will be demonstrated that his assumption is incorrect.

An example of a general case can be studied by comparing Fig. 3 with Fig. 1. In these gnomograms the positions of the faces are identical but the primitive parallelograms are different because of a difference in the choice of the crystallographic axes. Calling the crystallographic description of Fig. 3 the "old" and that of Fig. 1 the "new" setting, one finds that the "old" symbols of the "new" axes are [100], [021] and [001]. The unit face being the same in both cases, the relation between the new and the old indices of a face is

$$p':q':r' = p' : \frac{2q+r}{3} : r.$$

Taking now (Fig. 3) the faces $(021) = \pi_1$ and $(0\bar{2}1) = \pi_2$, one finds $\pi_3 = (002) = (001)$. Further

$$p_1' = 0, \quad q_1' = 3 \frac{2 \times 2 + 1}{3}, \quad r_1' = 3 \times 1 \text{ (thus } a_1 = 3)$$

$$p_2' = 0, \quad q_2' = \frac{2 \times \bar{2} + 1}{3}, \quad r_2' = 1 \text{ (thus } a_2 = 1).$$

Therefore

$$\pi_4 = (0 + 0, 5 + \bar{1}, 3 + 1) = (011) \text{ (Fig. 1) or } (0\bar{1}1) \text{ (Fig. 3)}.$$

Hence π_3 and π_4 , in this case, are different faces.

The weak point in Viola's argument lies in the fact that he tries to give a *general* demonstration for a thesis that has only a *restricted* validity. Viola speaks about indices without mentioning the crystallographic axes and the unit face that gives those indices their very meaning. Obviously he thinks he can prove his thesis if the axes and the unit face are, respectively, three arbitrary non coplanar crystal edges and an arbitrary suitable crystal face. We saw however that under these circumstances the thesis has no general validity. If, on the contrary, the axes and the unit face have been chosen under guidance of the crystal symmetry according to the orthodox crystallographic rules, it is a different matter. Then the thesis is true and this might be the cause of the unusual fact that for forty years no objections have been raised against Viola's argument.

On the assumption that the axes and the unit face have been chosen according to the usual crystallographic rules, we will now proceed to consider the various crystal systems.

Cubic System. Take two faces $(h_1k_1l_1)$ and $(h_2k_2l_2)$ of a hexoctahedron $\{hkl\}$; from the center drop perpendiculars n_1 and n_2 and observe that these have the same length d .^{*} Resolving n_1 and n_2 in the directions of

$$*d = \frac{a}{\sqrt{h_1^2 + k_1^2 + l_1^2}} = \frac{a}{\sqrt{h_2^2 + k_2^2 + l_2^2}}$$

the crystallographic axes we find the following components:

$$d^2 \times \frac{h_1}{a}; d^2 \times \frac{h_2}{a}; d^2 \times \frac{k_1}{a}; d^2 \times \frac{k_2}{a}; d^2 \times \frac{l_1}{a}; d^2 \times \frac{l_2}{a}.$$

Therefore the components of the resultant of n_1 and n_2 are:

$$d^2 \times \frac{h_1 + h_2}{a}; d^2 \times \frac{k_1 + k_2}{a}; d^2 \times \frac{l_1 + l_2}{a}.$$

Hence the resultant is perpendicular to the face $(h_1 + h_2, k_1 + k_2, l_1 + l_2)$. But the resultant of two equal vectors bisects the angle included by those vectors and therefore the face $(h_1 + h_2, k_1 + k_2, l_1 + l_2)$ is normal to the bisectrix of the angle between the faces $(h_1 k_1 l_1)$ and $(h_2 k_2 l_2)$, or in other words: the face $(h_1 + h_2, k_1 + k_2, l_1 + l_2)$ bisects one of the angles included by $(h_1 k_1 l_1)$ and $(h_2 k_2 l_2)$.

From this proof it will be clear that in the cubic system *the thesis is correct in all cases of two faces having the same distance d to the center*, i.e. not only for two faces of the same crystal form but also for two faces belonging to different forms, such as $\{322\}$ and $\{410\}$, or $\{510\}$ and $\{431\}$, or $\{552\}$ and $\{432\}$, etc. (cp. *Int. Tables Det. Cryst. Str.*, Vol. II, Chap. IX, p. 6). So, on choosing for $(h_1 k_1 l_1)$ any of the $48 + 48$ faces $\{322\} + \{410\}$ and for $(h_2 k_2 l_2)$ any other of those 96 faces, one finds the faces $(h_1 + h_2, k_1 + k_2, l_1 + l_2)$ and $(h_1 - h_2, k_1 - k_2, l_1 - l_2)$ to bisect the angles included by the former faces.

The Tetragonal, Hexagonal, Orthorhombic and Monoclinic Systems. In any gnomogram, the projection plane of which is normal to the crystallographic c -axis, the following theses hold true:

(a) The symbol of the middle point of the line joining the poles $(h_1 k_1 l)$ and $(h_2 k_2 l)$ is $(h_1 + h_2, k_1 + k_2, 2l)$, while the infinitely far point of the zone line $[(h_1 k_1 l), (h_2 k_2 l)]$ has the symbol $(h_1 - h_2, k_1 - k_2, 0)$.

(b) The angle-point W of a zone line is on the perpendicular drawn from the center C of the gnomon-circle on that zone line. In case this perpendicular passes through the middle point of the line joining $(h_1 k_1 l)$ and $(h_2 k_2 l)$, the faces $(h_1 + h_2, k_1 + k_2, 2l)$ and $(h_1 - h_2, k_1 - k_2, 0)$ bisect the angles included by the faces $(h_1 k_1 l)$ and $(h_2 k_2 l)$.

(c) Given a pole p_1 , the pole p_2 satisfying the condition that the "derived" faces, whose symbols are deduced from those of p_1 and p_2 by addition and subtraction, bisect the angles included by p_1 and p_2 , is found as follows:

- (1) draw with the point C as center a circle passing through the pole p_1 ;
- (2) any pole in the circumference of this circle having its third index equal to the third index of p_1 meets the qualifications of p_2 .

By way of example, Fig. 4 is a gnomonic projection of a ditetragonal bipyramid $\{hkl\}$, with the constructions of the angle-points W_1 and W_2 of the zone lines $[(hkl), (\bar{k}hl)]$ and $[(h\bar{k}l), (k\bar{h}l)]$. It will be clear at once that the lines which join the poles (hkl) and $(\bar{k}hl)$ to the center C form with

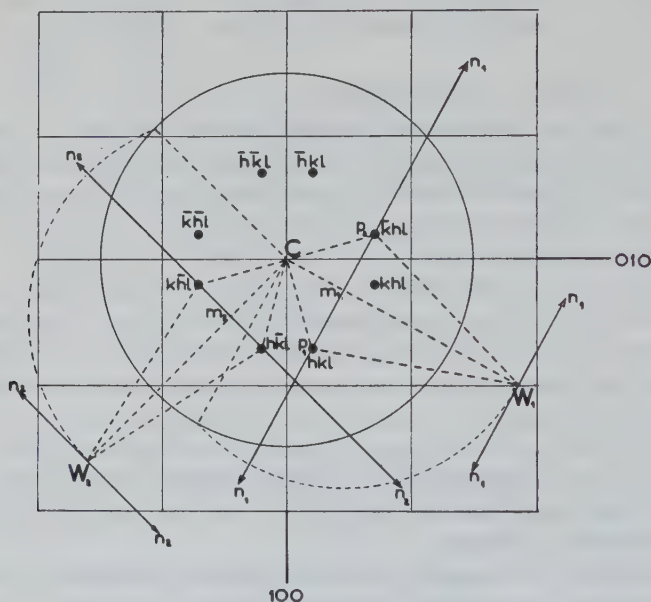


FIG. 4

the zone line an isosceles triangle and that therefore $\angle p_1 W_1 m_1 = \angle p_2 W_1 m_1$. Hence the faces m_1 and n_1 bisect the angles included by p_1 and p_2 .

Taking into account Goldschmidt's gnomonic theorem one finds for the indices of m_1 and n_1 $\left(\frac{h-k}{2l}, \frac{k+h}{2l}, 1\right)$ or $(h-k, k+h, 2l)$ and $(h+k, k-h, 0)$.

Taking the side of the "primitive square" as unit of length, the distance of a pole (hkl) to the center C in a tetragonal gnomogram is

$\sqrt{\left(\frac{h}{l}\right)^2 + \left(\frac{k}{l}\right)^2}$. Hence the poles $(h_1 k_1 l)$ and $(h_2 k_2 l)$ are on the circumference of a circle whose center is in C , if $h_1^2 + k_1^2 = h_2^2 + k_2^2$. Therefore Viola's thesis holds true in the tetragonal system for any two faces $(h_1 k_1 l)$ and $(h_2 k_2 l)$ satisfying the so-called "quadratic form" $h_1^2 + k_1^2 = h_2^2 + k_2^2$ i.e., not only for any two faces of a crystal form but also for the faces (671) and (291) , for instance. To take into account faces whose

third index has the negative sign it is a good plan to replace a face (pql) by the parallel face $(\bar{p}\bar{q}l)$, which has its pole in the gnomogram.

In a hexagonal gnomogram the distance of a pole (hkl) to the center C is $2\sqrt{\left(\frac{h}{l}\right)^2 + \left(\frac{k}{l}\right)^2 + \frac{h}{l} \frac{k}{l}}$. Hence the poles (h_1k_1l) and (h_2k_2l) are on the circumference of a circle whose center is in C , if $h_1^2 + k_1^2 + h_1k_1 = h_2^2 + k_2^2 + h_2k_2$. Therefore Viola's thesis holds true in the hexagonal

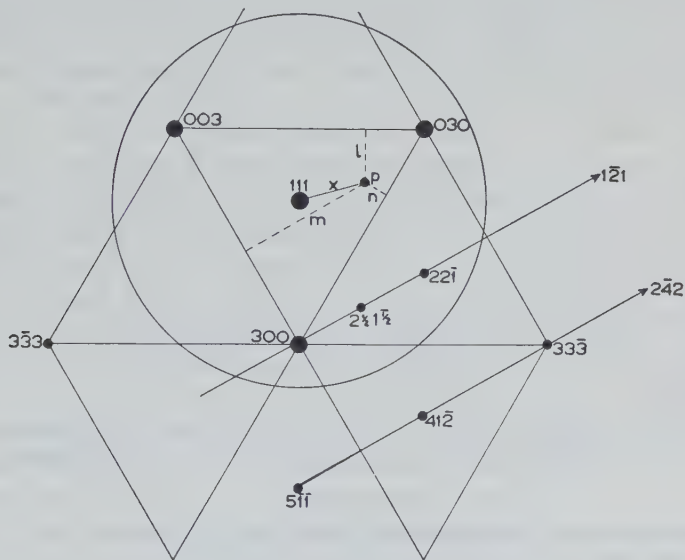


FIG. 5

system for any two faces (h_1k_1l) and (h_2k_2l) satisfying the quadratic form $h_1^2 + k_1^2 + h_1k_1 = h_2^2 + k_2^2 + h_2k_2$, i.e., not only for any two faces of a crystal form, but also for the faces (652) and (912) , for instance.

The orthorhombic system offers no difficulties, nor does the monoclinic system, provided the plane of projection in the latter case is chosen normal to the crystallographic b -axis. In both systems Viola's thesis holds true for any two faces of a crystal form.

Trigonal crystals that are described in Miller's system must be treated separately because, in their gnomograms, the plane of projection is not normal to any crystallographic axis. Consequently with these crystals the indices are read off in quite a different manner, namely by drawing through the pole p the perpendicular distances l , m , n to the sides of the "base-triangle" (Fig. 5) and seeking three numbers in the ratios $l:m:n$, whose sum is 3.

The distance of a pole p to the center of the gnomon circle is

$$\frac{2}{3}\sqrt{(l^2 + m^2 + n^2) - (lm + ln + mn)}.$$

Therefore the indices $(p_1q_1r_1)$ and $(p_2q_2r_2)$ of two poles that are at the same distance from the center of the gnomon circle satisfy the condition:

$$p_1^2 + q_1^2 + r_1^2 - (p_1q_1 + p_1r_1 + q_1r_1) = p_2^2 + q_2^2 + r_2^2 - (p_2q_2 + p_2r_2 + q_2r_2).$$

Besides any two faces of the same crystal form, there are many pairs of faces belonging to different forms that satisfy this condition; for instance, (300) and (221) or $(5\bar{1}\bar{1})$ and $(3\bar{3}\bar{3})$. More examples can easily be found with the help of *Int. Tab. Det. Cryst. Struct.*, Vol. II, Chap. IX, p. 4. In all those cases Viola's thesis holds true, i.e. the "derived" faces bisect the angles included by the "given" faces. The sum of the indices of the face found by adding the indices of the given faces will be 6. Before inserting this symbol in the gnomogram, the indices may therefore be divided by 2, in order to maintain the rule that the sum of the indices of a face be always 3. The sum of the indices of the face found by subtracting the indices of the given pair of faces is zero. This indicates that the face is parallel to the zone [111] and that its pole is infinitely far away. Examples are: $(5\bar{1}\bar{1})$ and $(3\bar{3}\bar{3}) \rightarrow (4\bar{1}\bar{2})$ and $(2\bar{4}\bar{2})$, or (300) and $(2\bar{2}\bar{1}) \rightarrow (2\frac{1}{2}, 1, \frac{1}{2})$ and $(\bar{1}\bar{2}1)$.

Acknowledgment. Prof. J. D. H. Donnay kindly supervised our translation. We are anxious to tender our thanks for his helpful criticism.

REFERENCES

- (1) NIGGLI, P. *Lehrbuch der Mineralogie und Kristallchemie*, Teil I (1941), 131.
- (2) KLOCKMANN'S, *Lehrbuch der Mineralogie*, neu herausgegeben von P. Ramdohr. (1942), 29.
- (3) VIOLA, C. *Zeits. Kryst.*, **40**, 280 (1905).

TINTICITE, A NEW MINERAL FROM UTAH*

BRONSON STRINGHAM, *University of Utah, Salt Lake City, Utah.*

ABSTRACT

A creamy white clay-like substance with unusual optical and chemical properties was found as a wall coating in a limestone cave near the Tintic Standard Mine in the Tintic Mining District, Utah. The chemical analysis and *x*-ray comparative data shows the mineral to be new and is here named tenticite. Its composition is $2\text{FePO}_4 \cdot \text{Fe}(\text{OH})_3 \cdot 3\frac{1}{2}\text{H}_2\text{O}$, with an index between 1.74 and 1.75; hardness 2.5, and specific gravity 2.82. Stereo electron-micrographs show the crystals to average about one micron in greatest dimension and that they perhaps crystallize in the orthorhombic system. The limestone surrounding the cave carries pyrite, which accounts for the iron, while the phosphate is derived from bat guano on high ledges of the cave.

INTRODUCTION

In 1944 while studying the alteration associated with hidden ore bodies in the Tintic Mining District, Utah, Dr. T. S. Lovering of the U. S. Geological Survey, collected a substance which possessed physical properties much like clay. Examination of the material by the writer revealed unusual optical properties for clay. From a chemical analysis made by Dr. Randall E. Hamm, University of Utah, it was found that Fe_2O_3 , P_2O_5 , and H_2O were present in proportions unlike any known mineral. A check analysis consequently was made with results very similar to the first. Powder patterns of the Tintic mineral and beraunite, which is of similar composition, were found to be different by the Bureau of Mines, Salt Lake City, and by Mr. J. M. Axelrod of the Geological Survey. It seems justifiable therefore to conclude that the substance is a new mineral. The name tenticite, after the locality where it is found, is proposed for this new phosphate.

PHYSICAL PROPERTIES

It will be shown later that crystals of tenticite vary in size from .3 mc. to 1.67 mc. in greatest dimension, consequently no megascopic crystals are observable. The material appears to be a dense, earthy, compact, porcelain-like mass filled with innumerable veinlets of greenish-brown jarosite. The pure tenticite has a creamy white color with a slight tinge of yellowish green. Since the material is composed of submicroscopic crystals the true hardness could not be determined, but the compact aggregates can be easily scratched with the fingernail, although there is no soapy feel to the powder. When chewed it is not gritty, but neither is it smooth like the clay minerals. A hardness of 2.5 therefore seems most descriptive. The specific gravity was determined by the pycnometer

* Published by permission of the Director, U. S. Geological Survey.

method and was found to be 2.82. It is insoluble in H_2O , H_2SO_4 , and HNO_3 , but slowly soluble in HCl . In H_2O however, there is a rapid dissociation of the crystals which, when agitated, form a near colloid. It readily yields water in the closed and open tubes and before the blow pipe fuses quickly to a black slag.

OPTICAL PROPERTIES

In a thin section of tinticite no structure whatsoever is discernible. Small thin fragments in index oils are colorless, but the larger, thicker fragments show a faint yellowish green. With crossed nicols there appears a confused aggregate polarization of low birefringence. Even under very high magnification individual crystals, of course, cannot be resolved, but thin edges of fragments show low gray interference colors. The mean index is near 1.745, and the birefringence is estimated to be about 0.005 to 0.007. This latter value is based partly on the fact that all indices seem to be below 1.75 and above 1.74.

CRYSTALLOGRAPHY

An electron micrograph of tinticite made by the American Cyanamid Company showed such well formed crystals that it was thought there might be a possibility of determining the crystal forms if a stereo electron micrograph were available. Professor L. Marton of Stanford University graciously supplied a stereo pair which shows the third dimension rather well.† This stereo pair (Fig. 1) is herein reproduced intact so that anyone might view them with a simple parlor stereoscope.

X-ray studies of the mineral definitely rule out the possibility of the crystals being isometric, tetragonal, or hexagonal, and after studying the stereo pictures, it appears that of the other three systems, the crystals seem to best fit the requirements of the orthorhombic system. In all, five different electron micrographs were taken of the mineral. The crystals appear to be oblong and tabular, the largest of which was 1.67 microns in greatest dimension, while the smallest was 0.3 micron, with the general average being around one micron. The thickness measured on the stereo picture is about $0.1 \pm$ micron. No angles, of course, could be accurately measured, but those crystals which appear to lie flat have approximately 90° corners, while those lying at angles seem to show a side pinacoid and a front dome, in addition to the flat tabular faces.

Figure 2 is an attempt to show the interpreted form of a typical crystal and is here offered for what it might be worth. One crystal appears to be

† For a description of the method employed in taking this stereo electron micrograph see Marton L., Stereoscapy with the electron microscope, *Jour. Applied Physics*, **15**, No. 10, 726-727 (1944).



FIG. 1. Electron micrograph stereo pair of tincticite. $\times 9200$.

warped but yet not fractured. This was probably done while the microscopic mount was being prepared and suggests that the crystals can be rather easily deformed.

COMPOSITION

In selecting the material for analysis it was necessary to exercise great care in order to exclude the jarosite veinlets. Fortunately the veinlets are all large enough to be ordinarily visible, but any finely disseminated



FIG. 2. Crystal of tinctite. Interpretation from electron micrograph stereo pictures.

jarosite could not be separated. The analyses therefore show small amounts of SO_3 , Na_2O , and K_2O , all of which can be accounted for by the presence of small amounts of jarosite and natro-jarosite. On some fragments, when treated with HCl , a very slight effervescence is observed, thus accounting for the CaO . The impurities responsible for SiO_2 , Al_2O_3 , and FeO were not detected, but the amounts of these are so small that they can be disregarded in calculating a formula.

ANALYSIS OF TINCTITE

	R. E. HAMM, <i>analyst</i> Univ. of Utah	LEE C. PECK, <i>analyst</i> Univ. of Minn.
SiO_2	—	.19
Al_2O_3	—	.18
Fe_2O_3	49.28	48.84
FeO	—	.00
MgO	—	.24
CaO	—	.36
Na_2O	—	.45
K_2O	—	.32
$\text{H}_2\text{O}+$	17.21	18.42
$\text{H}_2\text{O}-$	1.72	1.32
TiO_2	—	.04
P_2O_5	30.21	28.40
SO_3	.71	1.07
	<hr/> 99.13	<hr/> 99.83

Recalculating the Fe_2O_3 , P_2O_5 , and $\text{H}_2\text{O}+$ to 100% the following values are found:

	HAMM	mol.	PECK	mol.
Fe_2O_3	50.96%	.319	51.05%	.319
P_2O_5	31.24%	.220	29.69%	.209
H_2O	17.80%	.989	19.26%	1.070
	100.00%		100.00%	

The formula is then $3\text{Fe}_2\text{O}_3 \cdot 2\text{P}_2\text{O}_5 \cdot 10\text{H}_2\text{O}$, which when simplified is $2\text{FePO}_4 \cdot \text{Fe}(\text{OH})_3 \cdot 3\frac{1}{2}\text{H}_2\text{O}$.

X-RAY DATA

Through the courtesy of the U. S. Bureau of Mines, Salt Lake City, and the kind cooperation of Dr. E. Vernon Potter and Mr. Ralph W. Huber of that institution, an x-ray photograph of tinctite was made and the following data are the result of their work. The picture was taken using the powder method, on a General Electric machine generating 40 KVP and 9 milliamps. Fe- K_α radiation was employed with exposure of $1\frac{1}{2}$ hours. The darkest lines of the estimated intensities are 6 and the weakest less than 1. A definite number was not assigned to any line having an intensity below 1. Density values were made of the darkest lines on a Leeds and Northrup microphotometer.

TINCTICITE, $2\text{FePO}_4 \cdot \text{Fe}(\text{OH})_3 \cdot 3\frac{1}{2}\text{H}_2\text{O}$ FROM TINTIC, UTAH

<i>D</i>	<i>Est. Int.</i>	<i>Density</i>	<i>D</i>	<i>Est. Int.</i>	<i>Density</i>
6.70	4	.13	2.12	<1	
6.07	5	.14	2.09	<1	
5.67	5	.18	1.974	<1	
4.56	4	.14	1.941	<1	
4.38	2	.09	1.911	<1	
3.91	6	.23	1.873	<1	
3.28	6	.22	1.824	<1	
3.16	1	.07	1.710	<1	
3.01	6	.19	1.649	<1	
2.96	3	.11	1.586	<1	
2.59	<1	—	1.551	<1	
2.51	<1		1.517	<1	
2.44	<1		1.504	<1	
2.39	<1		1.475	<1	
2.35	<1		1.434	<1	
2.25	<1		1.409	<1	

OCCURRENCE AND ORIGIN

Not far from the Tintic Standard Mine is a shallow cave in limestone. The rocks surrounding the cave are heavily stained with limonite and

manganese oxide, indicating that the ground has been mineralized to some extent. The tenticite occurs associated with jarosite and limonite on the lower walls and floor of the cave as a plaster varying in thickness from a few inches to a foot or more.

When it was discovered that the tenticite was a phosphate the problem arose as to the source of this material. The cave is in Cambrian limestone which contains no known phosphatic beds. In studying the mineralization of Tintic no other phosphatic minerals had been found. The iron and sulphate of the jarosite were easily accounted for by the former presence of pyrite. The phosphate problem was solved however when careful search of the upper walls of the cave revealed considerable quantities of guano. Therefore the mineral was likely formed by meteoric waters seeping down over the walls of the cave, picking up phosphate from the guano and iron from the pyrite and precipitating the tenticite in the lower parts of the cave. The jarosite found with the tenticite invariably shows evidence of having formed late. This is expectable since where both sulfate and phosphate are available to combine with iron, the phosphate always forms first, and no iron sulfate will be precipitated until all of the phosphate is used up.

ACKNOWLEDGMENTS

Acknowledgments are made to the following: To Dr. Randall E. Hamm, University of Utah, and Mr. Lee C. Peck, University of Minnesota, for their careful analytical work. To the University of Utah Experiment Station and Research Committee which supplied the funds for analysis and for typing the manuscript. To Dr. L. Marton and his assistant, Miss Marjorie B. Glathe of Stanford University for the excellent stereo electron micrographs. To Dr. E. Vernon Potter and Mr. Ralph W. Huber and the U. S. Bureau of Mines for supplying x -ray information.

NOTES AND NEWS

AN ELECTRICALLY HEATED PLATINUM WIRE FOR USE IN THE MINERALOGICAL LABORATORY*

CHARLES MILTON AND H. CECIL SPICER

An electrically heated platinum wire has many advantages over the customary blowpipe-heated wire—in particular, facility in handling very minute particles, microscopic observation of the reactions employed, and easily-controlled temperatures exceeding those obtained by gas flames. The construction of such an apparatus is described.

Over fifty years ago Joly¹ described an apparatus he had invented and termed "Meldometer." It consisted essentially of a thin ribbon of platinum, about 1.2 mm. wide, through which an electric current, generated by a battery, was made to pass: the consequent heating of the ribbon caused mineral powders placed on it to melt, and by use of a microscope conveniently placed, the melting phenomena could be directly observed. Furthermore, by observing the measured thermal expansion of the ribbon, previously calibrated against the known melting points of substances such as potassium nitrate, silver chloride, silver sulfate, silver, gold, palladium, etc., Joly determined the melting points of many minerals. This was apparently Joly's chief concern, but part of his paper is devoted to discussing other uses of the instrument in determinative mineralogy—in particular, the formation of characteristic sublimates and the use of the ribbon, or preferably a coiled wire loop, with microcosmic salt or sodium carbonate as a flux to perform bead tests. The use of the instrument for melting point determinations was criticized unfavorably by Day and Allen² as involving subjective factors in measurement; however, they observe that "Its value for qualitative study, and in cases where only a very minute quantity of a substance is available is unquestioned."

Joly's paper was followed a few years later by one by Cusack,³ in which the instrument as manufactured by a Dublin firm of instrument makers is described and pictured. The paper gives a large number of melting-point determinations. The appearance of the instrument, as illustrated, is rather formidable, and, as above mentioned the results obtained were ad-

* Published by permission of the Director, Geological Survey, United States Department of the Interior.

¹ Joly, J., On the determination of the melting points of minerals. Part I, The uses of the meldometer: *Proc. Royal Irish Acad.*, **3**, 38 (1891).

² Day, Arthur L., and Allen, E. T., The isomorphism and thermal properties of the feldspars: *Carnegie Institution* (pp. 18–19), Washington, D. C. (1905).

³ Cusack, Ralph, On the melting points of minerals: *Proc. Royal Irish Acad.*, 3d Series, **IV**, 399–413. Dublin (1896).

versely criticized. Possibly for these reasons the underlying idea of the apparatus seems to have passed into oblivion among mineralogists; however, the undoubted advantage of a controlled source of heat, highly localized and varied at will, with temperatures obtainable exceeding those by the blowpipe, and, not the least, the facility of microscopic observa-



FIG. 1. Electrically-heated platinum wire in use.

tion of tests on extremely minute particles, seem to have been unwarrantably neglected.

With these considerations in mind, a modernized version of Joly's apparatus has been designed and constructed (by H. C. S.) and found to be of definite value in the mineralogical work of the Geological Survey. Its simplicity and cheapness (not exceeding \$20.00), and convenience (employing ordinary 110 volt alternating current) suggest that it may be

widely used, once its advantages are appreciated.

The details of construction are shown in the accompanying diagram, with a photograph of the apparatus, as set up in use.

The essential components are: a switch, a variable transformer (or rheostat), step-down transformer, plug-in type electrodes for holding the platinum wire, and a suitable box for mounting the parts. The step-down transformer is the most important item, and should have ample output



FIG. 2. Upper—Diagram of electrical connections. Lower—alternative set-up, using rheostat in place of variable transformer.

current in order to heat the wire to incandescence. The transformer for the original apparatus was reconstructed from one salvaged from an old radio A-B power supply which had a primary input of 120 volt-amperes. The secondary was rewound with the proper number of turns of No. 10 B & S gauge copper wire to give approximately 2.2 volts at full load current of 45 amperes.

The primary input is controlled by a Variac type 200-B variable transformer and gives smooth, uniform control of the current output and the wire temperature. A rheostat of ample capacity would also be satisfactory as would a Varitran variable transformer. The secondary of the step-down transformer is connected to the self-supporting binding posts for holding the heater wire through banana jacks and plugs and No. 10 hard brass rod. Connections and other details will be apparent from the figures.

A NEW OCCURRENCE OF GRIPHITE¹HOWARD W. JAFFE²

Recently, the College Park Division, Metallurgical Branch, Bureau of Mines, was called upon to identify two mineral samples submitted by the Foreign Economic Administration. According to information furnished by that agency, both samples were obtained from a deposit near Mt. Ida, about 100 miles northwest of Alice Springs, Northern Territory, Australia. One of these was identified as tantalite-columbite, and the other proved to be a complex fluophosphate of manganese, iron, aluminum, calcium and the alkalis. The latter material is now identified as griphite, considered by Dana to be a problematical phosphate.

This material occurs in brownish-black reniform masses, some of which contain a surface coating of iron and manganese oxides. It is vitreous to resinous in luster and brittle, and shows a conchoidal fracture. The specific gravity, as determined with the Jolly balance, is 3.43 and the hardness between 5 and 6. It is greenish-brown in transmitted light and optically isotropic. Its refractive index is variable within the range of 1.630 to 1.660. The material selected for analysis was essentially homogeneous. Other pieces contained microscopic impurities, of which muscovite, quartz, lazulite and goethite were identified.

A chemical analysis by R. Dwiggins and A. Yelmgren is as follows:

P ₂ O ₅	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	CaO	Na ₂ O	K ₂ O	Li ₂ O	F	Cl	H ₂ O
39.15	9.44	6.95	10.67	18.12	5.98	3.47	0.18	0.47	3.03	0.12	2.62 = 100.20

Spectrographic analysis shows a large trace of silica and minor traces of Cr, Sn, V and Be. Tests made with a Geiger-Müller counter indicate that it is slightly radioactive, although the source of the activity could not be detected spectrographically.

Griphite has previously been reported from only two localities, both in South Dakota. It was first described as triplite by L. G. Eakins (1) in 1890. Eakins' material came from a tin mine near Rapid City, S. D. He writes, "In reality, it probably represents a mixture but in general appearance it seems to be fairly homogeneous and in composition it approaches closely to triplite." Apparently Eakins did not attach much significance to the relatively high Al₂O₃ content or regarded it as a contamination from another mineral. The host rock is not described, but the association of the phosphate with tin suggests pegmatite. Griphite was named by W. P. Headden (2) in 1891 from *γριφος*, an enigma, "in allu-

¹ Published by permission of the Director, Bureau of Mines, U. S. Department of the Interior.

² Petrographer, College Park Division, Metallurgical Branch, Bureau of Mines, College Park, Maryland.

sion to its unusual and somewhat enigmatic composition." Headden's material was from the Riverton tin lode near Harney City, Pennington County, S. D. Headden says "It occurs in the granite common to the district, in kidney-shaped masses, some of them weighing upwards of fifty pounds, but they are not numerous." Headden's granite is undoubtedly one of the South Dakota tin-bearing pegmatites described by F. L. Hess (3) and subsequent investigators.

The analyses of Eakins (a), Headden (b) and Dwiggins and Yelmgren (c) compare favorably, the principal difference being a higher iron to manganese ratio in the Australian sample. McConnell (5) obtained an

	P ₂ O ₅	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	CaO	Na ₂ O	K ₂ O	Li ₂ O	F	Cl	H ₂ O
(a)	39.68	8.74	2.36	1.97	29.13	6.72	5.25	tr.	0.13	2.35	0.25	3.67
				(SiO ₂ 0.43		CO ₂ 0.26)=100.94						
(b)	38.52	10.13	—	4.00	29.64	7.62	5.52	0.30	tr.	tr.	0.11	4.29
				(insol. 0.16)=100.29								
(c)	39.15	9.44	6.95	10.67	18.12	5.98	3.47	0.18	0.47	3.03	0.12	2.62
												=100.20

x-ray powder-diffraction pattern of Headden's material and described griphite as a hydrophosphate garnetoid. The Australian material gives no discernible powder-diffraction pattern with Cu, Mo or Fe radiation and appears to be amorphous in the natural state. Upon heating it to be-

(C)-Griphite, Australia

<i>d</i>	<i>I</i>
3.40	s
—	
3.09	m
2.99	m
2.89	m
2.76	s
2.51	s
—	
—	
2.29	w
—	
1.84	w
—	
1.70	w
1.65	w
—	
—	
—	
1.48	w
—	
—	
—	

(M)-Griphite, South Dakota

<i>d</i>	<i>I</i>
3.39	1
3.264	$\frac{1}{2}$
3.066	4
2.97	4
2.884	1
2.743	10
2.498	4
2.408	1
2.362	1
2.281	3
2.018	3
1.832	2
1.770	2
1.700	3
1.637	6
1.604	1
1.563	1
1.536	1
1.478	2
1.344	1
1.325	1
1.303	1

tween 300°C. and 500°C., H. F. Carl obtained a powder-diffraction pattern (C) with an automatic recording Philips x -ray spectrometer which compares favorably with that obtained by McConnell (M) with unfiltered iron radiation. The crystallinity of the Australian material may be similar to that of certain tantalum-columbium minerals. Fergusonite, for example, is normally amorphous in the natural state but becomes crystalline after being heated to 400°C. (4).

ACKNOWLEDGMENT

The work reported in this paper was done under the general direction of J. B. Zadra, Chief, College Park Division, Metallurgical Branch, and under the immediate supervision of Alton Gabriel. The chemical analyses were made by R. D. Dwiggins and A. E. Yelmgren, the x -ray data were furnished by H. F. Carl and the spectrographic data by M. J. Peterson, all of the College Park Division, Metallurgical Branch staff. Their contributions are gratefully acknowledged.

REFERENCES

- (1) EAKINS, L. G., *U.S.G.S., Bull.* **60**, 135 (1890).
- (2) HEADDEN, W. P., *Am. Jour. Sci.*, 3d Ser., **41**, 415 (1891).
- (3) HESS, F. L., *U.S.G.S., Bull.* **380**, 131 (1909).
- (4) DANA, E. S., *A Textbook of Mineralogy*, 4th Ed., 710 (1932).
- (5) MCCONNELL, D., Graphite, a hydrophosphate garnetoid: *Am. Mineral.*, **27**, 452-461 (1942).

LOELLINGITE FROM ARIZONA

CHARLES A. RASOR, *Phoenix, Arizona.*

Loellingite (FeAs_2), a comparatively rare arsenic mineral, has been identified as a minor constituent of a zinc-copper ore mined from the Copper World Mine near Yucca, Arizona. It is an uncommon mineral and believed not previously described from Arizona. A description of its occurrence, mineralogical associations and chemical analysis is of interest at this time.

The Copper World Mine was rehabilitated with a preliminary development loan from the Government to mine high grade zinc sulfide as an aid to the war effort. During the development program, the mine was visited periodically to check on the progress and to note any changes. In December, 1945, during a routine examination of the underground workings, a few small specimens of a heavy, bright-silvery looking mineral were pointed out as being new in the ore. Some of the miners had uncovered a boulder of this material about the size of a man's head on the fifty-foot level, and at that time they were much excited for they believed it to be a mass of solid silver. During this excitement much of the original boulder

had disappeared into the hands of inquisitive visitors and miners, but a sufficient amount was left and subsequently submitted for further study.

Part of the material was taken to the mineralogical laboratory at the University of Arizona, where through the courtesy of Dr. M. N. Short, some polished sections were made and examined under the reflecting microscope. Such an examination showed the loellingite essentially free of extraneous minerals. Only a few scattered blebs of sphalerite and chalcopryrite were observed.

Some fourteen analyses of loellingite¹ recently have been brought together and in order to compare the Arizona loellingite with them, a carefully selected sample of about 20 grams was submitted to the Arizona Testing Laboratory, Phoenix, Arizona, for a complete chemical analysis. Mr. Claude E. McLean, chemist, lists the following elements present:

Fe.....	25.76%
Co.....	0.10
Ni.....	1.55
As.....	65.57
S.....	2.73
Cu.....	0.40
Zn.....	0.15
Pb.....	0.05
Al ₂ O ₃	2.02
SiO ₂	1.30
MgO.....	0.14
CaO.....	0.11
	<hr/>
	99.88%
Mn*.....	0.01
Sb*.....	0.001-0.01
Ag*.....	0.001-0.01
Au*.....	0.001
Ga*.....	0.001

* These elements were determined with the spectrograph.

An interesting features of the analysis is the presence of sulfur and nickel, but neither one in sufficient amount to make the mineral a variety of loellingite. The presence of alumina, silica, magnesia and lime is accounted for by contamination of the sample from wallrock schist or tremolite gangue. The small amount of copper, lead and zinc comes from the presence of small blebs of sphalerite and chalcopryrite. Removal of the gangue and blebs of sulfides from the analysis will give the Arizona loellingite a close approximation to the ideal composition.

¹ *Dana's System of Mineralogy*, Seventh Edition, Charles Palache, Harry Berman and Clifford Frondel, Vol. 1, p. 305 (1944).

At the Copper World Mine, loellingite is a very minor mineral in a deposit consisting of a few simple sulfides. These minerals are sphalerite, most abundant; chalcopyrite, next; and pyrrhotite, minor; but more abundant than loellingite. Pyrite and galena have not been observed. The gangue mineral is tremolite, but some biotite-like micas were observed along the walls of the ore. The ore deposit is lenticular and parallels the foliation of the granitic schist. In less than eighteen months of operation this small deposit has produced over 1.5 million pounds of zinc, and may continue on as a small producer for many years. Thus with the reopening of a small mine rich in zinc sulfide ore, a mineral new to Arizona has been found.

Acknowledgments

The writer wishes to acknowledge the assistance of R. L. Dye and J. H. Bathrick, operators of the Copper World Mine, for saving several specimens of loellingite for future study, and to Drs. B. S. Butler and M. N. Short for permission to use the laboratory facilities at the University of Arizona.

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

The Academy of Natural Sciences of Philadelphia, January 3, 1946

Dr. W. Hersey Thomas presided, with 55 persons present. Dr. J. D. H. Donnay spoke on "DIFFRACTION OF X-RAYS IN CRYSTALS." He stated that d/n values had been tabulated for approximately 2500 substances. Mr. Birchall exhibited a small collection of minerals obtained by his son who was with the U. S. Army in Belgium.

February 7, 1946

Dr. Thomas presided; 54 persons were present. Mr. John Cochrane reviewed "THE INDUSTRIAL APPLICATIONS OF THE SULFUR GROUP ELEMENTS—SULFUR, SELENIUM, AND TELLURIUM." Mr. Kissileff described a trip to New Hampshire and Vermont with Mr. Gordon, exhibiting specimens from pegmatites.

March 7, 1946

Dr. Thomas was in the chair, with 72 persons present. Dr. Richard M. Foose spoke on "THE BROWN IRON ORES OF PENNSYLVANIA." By means of stratigraphic, structural and physiographic control, a large ore body was found at White Rocks in Cumberland County. Isopach maps of the overburden and ore body, and logs of drilling were shown. The paragenesis of the iron and manganese oxides was probable as follows: (1) replacement of clay by limonite of rust-brown color, (2) replacement by dark brown or black limonite, (3) replacement by manganese oxides, and (4) replacement by goethite. Associated minerals are: barite, sphalerite, pyrite, jasper, quartz, wavellite, colophonite. Impurities in the oxides include Co, Ni, Ti, V, etc. The concentration was probably affected by descending solutions from overlying, impure limestones.

Mr. Kissileff exhibited zeolites from Perkiomenville, Pa., and Mr. Jehle had on exhibition pyritic fossils from Germany.

April 4, 1946

Dr. Thomas was in the chair, with 60 persons present. Dr. John Putnam Marble addressed the society on "RANDOM REMARKS ON RARE EARTHS," with illustrations of deposits in the Kola Peninsula. The concentration of rare earths by some plants was alluded to, as well as the remarkable concentration in water-filled sink holes in Wyoming, in sufficient quantity to kill young trout. Mr. Morgan exhibited marcasite crystals from Blue Ball quarry, and Mr. Cochrane showed some calcite from the same locality. Mr. Gordon described barite and siderite from Frostburg, Maryland.

CHARLES A. BELZ, *Secretary*

THE NEW YORK MINERALOGICAL CLUB, INC.

Abstract of meeting of April 17, 1946

The speaker of the evening was Dr. Herman Yagoda who spoke on "ANALYTICAL PATTERN TECHNIQUES OF RADIO-ACTIVE AND LUMINESCENT MINERALS." The method consists in placing a polished surface in contact with a photographic emulsion desensitized to light. Either a physical or a chemical pattern may be obtained for study. The talk was illustrated with color lantern slides.

PURFIELD J. KENT, *Secretary*

Abstract of meeting of May 15, 1946

The speaker of the evening was Ralph J. Holmes, who spoke on the "OCCURRENCE OF NICKEL-COBALT MINERALS IN THE ZINC DEPOSIT AT FRANKLIN, NEW JERSEY." He showed that several specimens agreeing with the description of chloanthite, NiAs_2 , were complex mineral assemblages, instead of the single isometric arsenide. Skutterudite is present but is a very minor constituent, encrusting large nodular masses of rammelsbergite and pararammelsbergite, which are in part rimmed with gersdorffite. Veinlets of safflorite (?) transect the other arsenides. No loellingite was observed, but in some cases "halos" of arsenopyrite rim the nickel-cobalt minerals. This increases the number of species of important varieties at Franklin to 159. The talk was illustrated with color lantern slides.

Dr. F. H. Pough showed two extremely interesting colored motion pictures of volcanoes, one of Parícutin and the other of the eruption of Mauna Loa in 1942.

PURFIELD J. KENT, *Secretary*

DISCREDITED SPECIES

Hydrogiobertite, Hydrodolomite

S. CAILLÈRE, Contribution à l'étude de l'hydromagnésite et de quelques autres hydrocarbonates magnésiens: l'hydrogiobertite, l'hydrodolomite et la giorgiosite. *Bull. soc. franc. minéral.*, **66**, 55-70 (1943).

Optical, x-ray, and thermal study of hydrogiobertite and hydrodolomite from Vesuvius, the type locality, show these minerals to be mixtures of hydromagnesite and calcite.

MICHAEL FLEISCHER

NEW DATA

Giorgiosite

S. CAILLÈRE, *op. cit.*

Optical, x-ray, and thermal study of giorgiosite indicate that it is a distinct mineral species.

M.F.

NOMINATIONS FOR OFFICERS OF THE MINERALOGICAL SOCIETY
OF AMERICA FOR 1947

The Council has nominated the following as officers of the Mineralogical Society of America for the year 1947:

PRESIDENT: M. J. Buerger, Massachusetts Institute of Technology, Cambridge, Massachusetts.

VICE-PRESIDENT: Carl Tolman, Washington University, Saint Louis, Missouri.

SECRETARY: C. S. Hurlbut, Jr., Harvard University, Cambridge, Massachusetts.

TREASURER: Earl Ingerson, Geophysical Laboratory, Washington, D. C.

EDITOR: Walter F. Hunt, University of Michigan, Ann Arbor, Michigan.

COUNCILOR (1947-50): H. H. Hess, Princeton University, Princeton, New Jersey.

The twenty-seventh annual meeting of the Society will be held in Chicago, Illinois, December 26-28, 1946, in connection with the fifty-eighth meeting of the Geological Society of America. Headquarters will be at the Stevens Hotel, and the scientific sessions and social functions will be held there.

Members of the Society who are planning to present papers at the scientific sessions of the annual meeting should notify the Secretary as soon as possible in order to receive the proper blanks for their abstracts. All abstracts should be in the Secretary's office by *October 15*.

Advance announcement of the annual meeting will be distributed to members of the Society, with the ballot for officers, in the middle of October. The final program of the meeting, including the schedule of papers, abstracts, and other information will be sent to each member in December. Further specific information regarding the annual meeting may be obtained from the Secretary's office.

C. S. HURLBUT, JR., *Secretary*

Dr. Clifford Frondel has been appointed Associate Professor of Mineralogy and Curator of the Mineralogical Museum at Harvard University, filling the vacancy caused by the death of Dr. Harry Berman.

Professor Austin F. Rogers of Stanford University has been elected an Honorary Life Member of the East Bay Mineral Society of Oakland, California.
